LAND/WATER CLASSIFICATION

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LAND/WATER CLASSIFICATION

A Review of Water Classifications and Proposals

for Water Integration into Ecological Land Classification

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Environment Canada

Ottawa, Ontario

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Ecological Land Classification Series, No. 5

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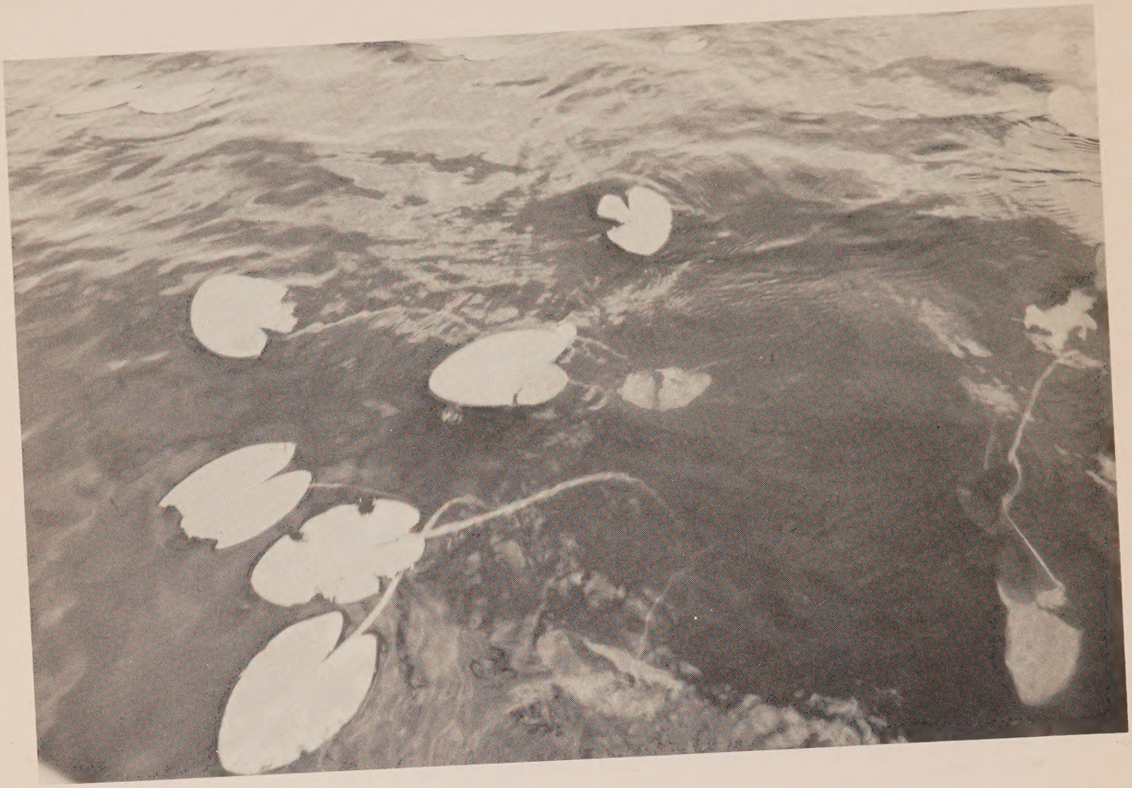

Figure 1

PRELUDE

Since the early 1960's there has developed in Canada a great deal of expertise in ecological (bio-physical) land survey. Initially this experience revolved around the Canada Land Inventory (CLI), a programme which produced maps, for the agricultural and settled parts of Canada, of land capability for forestry, agriculture, wildlife and recreation. In the late 1960's and the early 1970's informal discussions and formal workshops expressed a perceived need to extend land surveys to remote areas and at the same time to utilize an objective, descriptive approach to the presentation of data.

Under the auspices of the Canadian Forestry Service, the National Committee on Forest Land Subcommittee on Bio-physical Land Classification recommended in 1969 the adoption of a "bio-physical" approach to land mapping. This methodology follows the European "landscape" and the Australian "land systems" philosophies by which ecosystems are given tangible expression on the ground and are used as mapping units at various levels of perception. During the 1970's much bio-physical land survey has been conducted, mostly emphasizing landforms, soils and vegetation (Figure 2).

There is much informal agreement that, despite the wide application of bio-physical methods, there is a common failure to integrate data on aquatic resources, and that it is uncertain how aquatic data should be integrated with bio-physical data. This paper examines first the ecological significance of aquatic features and thus the need for related data in planning and management of natural resources. Secondly it describes some current approaches to integrated land and water classification and survey. Thirdly it reviews those parameters most useful and feasible to collect. Fourthly and last, it attempts to describe integrated units of land and water at various levels of mapping. I do not attempt to analyze why aquatic information is often lacking from bio-physical surveys (now called ecological land surveys), but instead to search for directions in which to rectify this absence.

Two questions inevitably arise: what is a water body, and what is an aquatic feature? Since there are many glossaries and papers which define all manner of natural features, I decline to propose yet one more for "water body" beyond saying "a lake or a river". For practical reasons only I exclude wetlands and marine coasts: these are well reviewed elsewhere in the bio-physical literature by Zoltai et al (1975) and Silk (1975) respectively.

An "aquatic feature" is any object related to a water body either by proximity or by actual process, including shorelines and backshores, river channels and their valley flats, lake bottoms, islands, deltas and so forth. Thus water bodies are contained in a combination of several aquatic features. Apart from these loose, ostensive definitions, I do not wish to add yet more to the present flood!

LAND SURVEY IN CANADA PRIOR TO 1978

Figure 2

Chapter One

THE NEED TO INTEGRATE WATER INTO LAND SURVEY

WATER IN THE LANDSCAPE

"Water is . . . a highly variable and mobile resource in the widest sense. Not only is it a commodity which is directly used by man but it is often the mainspring for extensive economic development, commonly an essential element in man's aesthetic experience, and always a formative factor of the physical and biological environment" (Chorley, 1969, p.3)

These formative roles include water regimes in soil formation, evapotranspiration, photosynthesis, and rainsplash erosion of cultivated fields. At a visible scale, the variety of lakes, rivers and shoreline types which cover the Canadian landscape attests to the pervasive importance of water as a resource. These resources supply water for consumptive use, they are used in industrial processing, fisheries, as objects for recreation and the aesthetic appreciation of the environment, and frequently are attractions for land-based activities. Therefore, to allow for ecologically sound environmental management, the recent and current efforts in ecological land classification and survey should be expanded to include water data (Canada Committee on Ecological Land Classification - CCELC, in Thie and Ironside, 1977).

Water bodies display a remarkable variety of types and features. In a simplistic, practical way one can consider water bodies as being either lakes, rivers or estuaries, each having a variety of shorelines, riverbanks, coastal or other aquatic features. When examined closely, however, these distinctions lose their clarity. For example, some rivers of the Canadian Shield widen sufficiently to become lakes. Some lakes have a morphology and water circulation such that they contain more than one limnological or hydrological system: these lakes may be said to contain several water bodies. Lagoons and marshes may be as large and important in the landscape as many whole but smaller lakes (Figure 3). In river networks there is a continuous spatial progression from small, ephemeral headwater rills to large estuarine meanders. As the view of rivers becomes more general, and as map scale diminishes, the essential properties of rivers change from the hydraulic to the morphologic to the topologic to the hydrologic (see Ch.5).

Rivers and lakes also demonstrate a number of cyclic and non-cyclic temporal properties. Changes in water level, the turnover of lakes, annual freezing and thawing, spring flood, and base flow hydrograph recession are widespread

Figure 3: Lagoons and Marshes may be as Large and Important in the Landscape as Many Whole but Smaller Lakes

phenomena. Even within small areas the day-to-day calendar of events can vary markedly depending on the size of the water body, its elevation, throughflow, shoreline development, bedrock and surficial geology. Equally notable are spatial changes in the nature and intensity of long-term, non-cyclic events. Erosion and sediment transport and deposition are intricate phenonoma with abrupt changes in space and time, and yet they are of great consequence to the planning and management of water bodies and adjacent lands. Eutrophication of lakes may be measured in years and in decades, but this is still a rapid process if we assume that ecologically sound planning must look to the longer future.

WATER AND PLANNING

The foregoing identifies some of the features which pose problems in classifying water bodies and aquatic features. At the same time, however, these examples hint at some reasons for including water data in the planning process of a region's resource development. These reasons stem from the fact that most of man's activity is in some way water-related, even when the prime focus is upon land (Figure 4).

"Water has played a vital role in transportation and communications, and its contributions in these areas in turn have influenced patterns of industrial growth and settlement in Canada" (Environment Canada, 1976a, p.16). This growth and settlement has involved municipal and rural domestic use, industrial and agricultural use, fishing and hunting, navigation, recreation and electric power generation (Ibid, p.5).

As the Canadian population and economy grow and develop, so too does the pressure on our natural resources. In order to minimize environmental damage and to optimize resource use and multiple use in the future *"planning must be supported by a carefully designed and adequate information system . . . A comprehensive and effective information system should relieve the individual from the tedious and sometimes impossible task of completely screening and selecting information from the overwhelming stock that is available . . ."* (Environment Canada, 1975, p.67-68).

Thus the needs of water resource planning coincide with those of land resource planning, namely the desire to have a single, integrated resource survey. An integrated approach to resource planning and management offers efficiency and recognizes the holistic nature of landscape and the many facets of human activity.

ECOLOGY AND LAND SYSTEMS

The holistic concept of landscape is not new. It is deeply rooted in the language and culture of many societies. As examples, Major (1969) offers such terms as heath (English), muskeg (Chippewa Indian), tundra (Siberian) and pampas (French). In the scientific community

Figure 4: Snow Disposal on River Banks; a Water-Related Land Activity.

Major gives credit to Von Humboldt in 1807 and Haeckel in 1866 for an ecological view of plants. During the last one hundred years the names of Sukachev and Tansley figure prominantly in the formulation of plant ecosystem concepts. The use of ecosystems in land classification stems largely from Dokuchaiev. This idea states that landscapes can be divided into more or less finite units within which environmental controls, plants and animals are interdependent and adjusted to one another.

Since World War II, the use of ecosystems for land classification has begun to be applied to the survey and planning of land resources in remote areas. In this approach the entire landscape is parcelled into contiguous units having ecological significance and which display a limited number of diagnostic features which are used in their delineation. These units have been given the names of *land systems, land units* and *land types* (Christian and Stewart, 1968), among others. In Canada the application of these ideas was pioneered, in the 1950's and 1960's, by Hills in terms of an ascending hierarchy of *site, site district* and *physiographic site types* (Hills, Love and Lacate, 1970). In 1969 the Sub-Committee on Bio-physical Land Classification adopted an ecosystem methodology in a proposal for a "bio-physical" (ecological) basis for land classification (Sub-Comm. Bio-phys. Land Classif., 1969). The ecological systems approach to natural resource surveys has since been given tangible approval by way of a number of provincial and federal ecological land surveys (Thie and Ironside, 1977).

"An (ecological land) survey . . . is carried out to provide a framework for environmental resource management using a hierarchical classification (which integrates a number of environmental elements)" (Environment Canada, 1976b, p.1). As described in the preceding paragraphs, the concept of land is central to the ecosystem approach to these surveys. A tract of land can be defined as *"a specified area of the earth's surface: its characteristics embrace all reasonably stable, cyclic or predictable attributes of the biosphere vertically above and below this area including those of the atmosphere, the soil, and the underlying geology, the hydrology, the plant and animal populations and the land cover resulting from human activity, to the extent that these attributes exert a significant influence on the present and future uses of the land by man"* (modified after Beek and Bennema, 1972).

ECOLOGICAL LAND SURVEYS AND WATER

Ecological land surveys are built upon the perception of boundaries which enclose surfaces displaying certain uniform or interconnected traits. These surfaces are contiguous and closely related to defined mapping scales. To provide a data base which is re-usable over several decades, the properties chosen are normally those that change little in human experience, such as climate, geomorphology, soils and vegetation chronosequence. It is not surprising, therefore, that water, with its long-distance flow and marked seasonal regimes, is examined only partially or not at all in ecological land surveys. Even water research has tended to define narrow limits of study by concentrating on one or other type of aquatic feature or water body (Platts, 1976a).

In Quebec, for example, the ecological surveys of the Saguenay-Lac St. Jean and James Bay areas restricted water data input to that of the morphological qualities of the land containing bodies of water (Jurdant et al, 1972, 1977). Although the wetland classification of Zoltai et al (1975) is national in scope, it is, of course, feature specific. The landscape classification of the delta of the Peace-Athabasca (Dirschl et al, 1974) is aimed at the study of plant successions, and is therefore restricted by objectives and to a particular aquatic feature. Land classification in Manitoba does not explicitly describe water in any way (Mills et al, 1976).

While land surveys in Canada have been constrained by region, needs, budgets or expertise, water research has been mainly discipline-oriented. Whole lakes have largely been the province of limnologists concerned with productivity (e.g. Rawson, 1960) or eutrophication (e.g. Dillon, 1975). Shorelines have been assessed mainly according to morphology and for recreation purposes (e.g. Ontario Ministry of Treasury, 1975). River basins are the domain of hydrologists concerned with water and nutrient budgets. Considerations of fish habitats, aesthetics or other recreational uses are commonly tackled independently and on smaller units of landscape.

The open water and wetland classification proposed by Adams and Zoltai (1969) states that a *"classification system must be oriented to serve the needs of several disciplines, (such) as wild ungulates, fish, waterfowl and furbearers (sic) as well as hydrology, forestry, recreation and agriculture"* (Ibid,

p.23). Despite the agreement with water planners that water should be included in integrated resource surveys, such integration in Canada is still in the formative stage. Not only is this fact illustrated by the foregoing examples, but even Adams and Zoltai's own water classification has limitations. It does not show how to integrate land and water at various mapping scales. It is hierarchic only in an informational sense for individual aquatic features: it is a taxonomic approach. A spatial hierarchy in the tradition of Christian and Stewert (1968) and of bio-physical mapping in Canada (Sub-Comm. Bio-phys. Land Classif., 1969) is present only in the context of dry-land units.

There is therefore a need for a philosophy and methodology which can integrate water into ecological land classification and mapping. As demonstrated above, a number of practical experiences have already been gained in Canada. Through an examination of these experiences, it may be possible to incorporate water into a feasible resource survey method, in such a way as to fill the data needs of a variety of users.

Chapter Two

LAND SURVEY AND WATER CLASSIFICATION

BIO-PHYSICAL (ECOLOGICAL) CLASSIFICATION

Introduction

The flowering of the ecosystem concept in Canadian land survey led, in the late 1960's, to the publication of Guidelines for Bio-physical Land Classification (Sub-Comm. Bio-phys. Land Classif., 1969). These Guidelines arose out of discussions and practical experiences in the field of land evaluation. A hierarchy of land divisions was proposed, ranging down in size from land regions, through land districts and systems to land types. The definitions of these units of land are of fundamental importance. Each level in the hierarchy is based on a number of environmental components. At differing scales and levels of mapping, data collection may focus on varying features and may require differing kinds and amounts of logistical support.

A Hierarchy of Land Mapping Units

According to the Guidelines for Bio-physical Land Classification, a land region is mappable at scales of 1:1,000,000 to 1:3,000,000 and *"is presently defined as an area of land characterized by a distinctive regional climate as expressed by vegetation"* (Ibid, p.4). A *"land district . . . is defined as an area of land characterized by a distinctive pattern of relief, geology, geomorphology and associated regional vegetation."* Within a climatically defined region, districts are therefore discriminated by physiography. They are mappable at scales between 1:1,000,000 and 1:500,000 (Ibid, p.5). A land system is more complex, being *"defined as an area of land throughout which there is a recurring pattern of landforms, soils and vegetation."* Land Systems are most effectively mapped at scales of 1:125,000 (Idem). A land type is an area of a uniform association of parent material, soil and vegetation chronosequence and is the smallest level in the hierarchy that displays long-term, permanent properties. They can usually be readily delineated at scales of 1:10,000 to 1:20,000 (Ibid, p.6). Smaller units, called land phases, can be distinguished by their homogeneity of soil development and vegetation stage. That is to say they are units of uniform vegetation within a land type (Jurdant et al, 1977). On air photos a land phase can be identified by uniform terrain characteristics and plant cover. Thus pervading the units of classification are various expressions and scales of climate, landform and materials, with the focus on the land type as the basic unit of classification, land systems as the most common mapping unit, and on air photo interpretation to provide the raw data.

Open Water Classification

Included with these Guidelines is the *"Proposed Open Water and Wetland Classification"* prepared by Adams and Zoltai and already referred to above (1969). Since the Guidelines and their classification have formed a springboard for subsequent developments in Canadian ecological land mapping, the principles behind the water classification are quoted here at length.

"1. *The classification should involve water and wetland classes that are significant from the standpoint of fish, wildlife and vegetation productivity.*
2. *The classification should be a hierarchical system permitting the workers to go to various levels of detail as described.*
3. *The classification should be relatively simple, involving easily recognizable wetland or water areas at the class level.*
4. *The classification of wetlands and open water should be possible from the interpretation of aerial photographs, at least at the class level. A further breakdown into subclasses and types is also feasible when supported by aerial reconnaissance and ground checking. Site descriptions are obtainable only from ground surveys.*
5. *The description and mapping of water and wetland classes should be integrated with the description and mapping of the related land components in the Bio-physical program.*
6. *The responsibility for the final delineation and appraisal of the wetland components should rest with the resource personnel engaged in the Bio-physical program*"

(Adams and Zoltai, 1969, p.24).

While these principles seem sound, several of them furnish difficulties in the particular context of integrating land and water into a unified ecological land classification. Concerning the first principle, there are other viable needs apart from those describing fish, wildlife and vegetation productivity. As noted at the start of this discussion, water resources can also be used for irrigation, domestic

consumption, waste disposal, thermal and hydroelectricity generation, navigation, aquatic sports, aesthetic appreciation and industrial processing.

Secondly, the bio-physical classification is built upon the principle of identifying units of land which at any given scale comprises a number of smaller units, so forming a spatial hierarchy based mainly on climate, geomorphology, soils and vegetation. Water, however, occurs in its own natural hierarchy called drainage systems. These are linear hierarchies which depend largely on topography, often transecting climatic, vegetational or physiographic boundaries.

As proposed by Adams and Zoltai's fourth principle, reliance upon air photos remains an efficient means of conducting ecological land surveys. However, the traditional single-date, panchromatic, medium-altitude photograph is inadequate for locating the uppermost limits of stream networks, for estimating the storage capacity of large channels, seasonal river regimes, or vertical temperature gradients in lakes, and for many other small size, non-areal or variable attributes of flow systems. Whereas land surveys are normally conducted from single-date aerial photography and single-visit ground checks, water surveys are normally spread over several visits, for each of several years, to a number of monitoring stations. Integrated land/water surveys must compromise by mapping those features that relate to and control the dynamic aspects of water.

Finally, the fifth principle calls for the integration of land and water in ecological land surveys, a principle already argued for in this paper. Unfortunately, the same fifth principle suggests that water mapping should be tied to land mapping units. This may be possible for many Canadian Shield and Prairie pothole lakes, but there are also many large rivers, great lakes, and lakes with short flushing times whose hydrology and limnology are not closely tied to neighbouring units of land. In short, one should not make *a priori* assumptions about applying a given ranking of units of land to water systems. It may be that the delineation of units of land should be based from the start on both land and water properties.

The open water classification proposed by Adams and Zoltai (1969, p.26) is shown in Table 1. Their chosen parameters are generally suitable for detailed, large scale mapping. However, there are a number of important criteria absent such as lake flushing, composite shorelines and depositional sites, or conflicting criteria, such as *basin topography* being, say, *meandering with oxbows*. A more rigourous partition of properties, more input of ground-based data than that which aerial photography can provide, and some philosophy for the areal grouping, or hierarchy, of open waters are needed. Alternatives for grouping could be based on one or several of the following: (1) drainage patterns, (2) drainage network topology, (3) units of land grouped according to climatic, geologic, topographic and vegetal controls over runoff response, (4) lake districts as a function of morphology or (5) the trophic status of lakes. In reality all these approaches have equal merit. Jeffrey's final statement (1969, p.61) that *"the extraction of mapping - classification data by computer should be kept in mind"* is one possible solution; one could maintain a data base of small units of land, and let a hierarchy for each feature define itself according to the users' needs. Jeffrey (1969) suggested that there are many qualitative applications at the reconnaissance level, and that *"hydrologic interpretation of the Bio-physical classification will probably most usefully be oriented towards the descriptions which accompany mapping rather than towards mapping itself"* (Ibid, p.61). The flexibility of verbal annotations may help resolve these problems of mapping and classification.

My conclusion is that the principles of Adams and Zoltai suffer only in being too limited in their scope. Without these limitations, I can agree on the need for a hierarchic mapping procedure which integrates land and water for a variety of uses and users and which is founded upon remote sensing techniques.

SERVICE DES ETUDES ECOLOGIQUES REGIONALES (SEER)

Introduction

The publication of the guidelines for bio-physical land classification was without doubt pivotal to the Canadian development of ecological land survey. Since then the most extensive work has been at the Service des Etudes Ecologiques Régionales (SEER) of Environment Canada at Quebec City. To date this work has been in two areas, the regions of Saguenay-Lac St. Jean and of James Bay. The principles behind this work are described by Jurdant et al (1975b). Although not explicity stated in their report, the word *"territoire"*, as in *"classification écologique du territoire"*, has a wider meaning in French than

have the English words *"land"*, commonly meaning dry ground and its soil, trees, etc., or *"territory"*, used for political units. *Territoire* is understood to include all the environments of an area, be they dry, wetland or water, and their related flora and fauna. Thus in Quebec the integration of water into ecological land surveys has likely been aided by etymology as much as by methodology.

Saguenay-Lac St. Jean

In the Saguenay-Lac St. Jean survey, water bodies were surveyed on the basis of air photo interpretation characteristics chosen mainly *"for the evaluation of the possibilities for recreational development of lakes and rivers"* (author's translation of Jurdant et al, 1972, prefix to Annexe 10), such as the locations of beaches, canoe routes and deep water navigation routes. Table 2 shows the classification used in this 1972 ecological land/water survey.

The authors indicate that their aquatic classification is largely inspired by the system proposed by Adams and Zoltai in 1969. However, a comparison shows that SEER limited themselves to morphologic parameters retrievable from air photographs, whereas Adams and Zoltai proposed the inclusion of qualitative expressions of water quality and of quantitative measures of shoreline materials. These properties would require, respectively, extensive ground truth and detailed shoreline interpretations from air photos. Instead, the SEER classification gives a more rapid, subjective approach to baseline surveys. Clearly there is a trade-off between increasing amounts of data, especially field data, and increasing costs for an ecological land/water survey.

James Bay

In the years since the Saguenay-Lac St. Jean survey, SEER has completed an ecological land survey of the James Bay area in Quebec (Figure 2) and is currently preparing reports on applications of their data to a variety of purposes (e.g. Jurdant, 1975a). Their aquatic classification is inherited from the Saguenay-Lac St. Jean experience, but with elaborations of the categories of aquatic ecosystem and of the abundance of streams and wetlands. The legend is closely tied to that for dry-land units, and mapping is performed for both dry-land systems and for ecosystems containing interrelated land and water bodies. Thus the ecologic maps contain overlapping land and water systems (Figure 5). Ecosystems can be interpreted separately or together, depending on the users' needs. The classification of aquatic ecosystems used in the James Bay surveys is shown in Table 3; only the water criteria are reproduced.

This revised aquatic classification suffers from the same absence of water quality and foreshore material data as does the Saguenay-Lac St. Jean ecological land survey. Also the parameters are scaled in a qualitative way, so that comparisons with other studies are difficult. Conversely, the strength of this land classification method lies in its ability to extrapolate, from the data base, a relative weighting value for a number of use potentials. Jurdant et al (1977) discuss a range of examples. A "potentiality" weighting is achieved by assigning values to each factor in a land system's legend, multiplying each by a relative weighting factor, and then totalling the numbers. The results can be portrayed by choropleth maps. This methodology, albeit subjective, is powerful because it is based on simple air photo criteria and analytical techniques understandable to users from all disciplines. While there may be gaps in the data inputs, this computer-compatible methodology for data storage and handling is certainly to be recommended for trial in other parts of Canada.

BRITISH COLUMBIA ENVIRONMENT AND LAND USE COMMITTEE (ELUC)

Recently developed in British Columbia is a system to classify, map and store data on aquatic systems. This aquatic mapping method contrasts with that of SEER in the Saguenay-Lac St. Jean and James Bay areas. Whereas in the Quebec experiences the mapped water bodies are predominantly lakes, in British Columbia they are mainly rivers and streams. Secondly, in Quebec the primary application of ecological water data is for the evaluation of recreation potentials; in British Columbia it is for fishery purposes. The latter is hardly surprising since the British Columbia system was composed at a workshop attended largely by persons with fisheries interests (ELUC, 1975).* Thirdly, in Quebec the mapping criteria are closely tied to air photo interpretation of ecological complexes at a scale of 1:125,000, whereas in British Columbia land features are portrayed at 1:50,000 to 1:20,000. One lesson is clear, that local needs and environments can generate very different responses to a situation. Consequently it is unrealistic and impractical to propose a definitive national

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* The British Columbia Environment and Land Use Secretariat is now known as the Resource Analysis Branch.

Table 1: The Open Water Classification Proposed by Adams and Zoltai (1969).

CLASS: STANDING OPEN WATER

Subclasses: Permanent - Deep, Shallow or Open Water Marsh.
Intermittent - Open Water
Drainage System: Open, Restricted or Closed.
Basin Topography: Horizontal - Regular, Irregular or Very Irregular.
Vertical - Gently, Moderately or Steeply Sloping.
Water Type: Soft, Hard, Brackish or Saline.
Site Description: Percent Shoreline in Rock, Mud, Sand and Gravel, and Peat.
Vegetation.
Backshore Slope.
Erosion.

CLASS: RUNNING WATER

Subclasses: Permanent, Periodical or Intermittent.
Deep, Moderately Deep or Shallow.
Basin Topography: Horizontal - Straight, Curved, Sinuous, Meandering with Oxbows, Braided, Beaded or Dendritic.
Vertical - Gently, Moderately or Steeply Sloping.
Water Type: Clear, Stained or Turbid.
Site Description: Shoreline Material, Vegetation, Gradient or Velocity.
Volume of Flow, and Erosion.

CATEGORY OF AQUATIC ECOSYSTEMS

a) Land system of <5% of its area covered by lakes or rivers.
b) Land system with 5%-15% of its area covered by lakes.
c) Land system bordering the Saguenay.
d) Land system bordering Lac St. Jean.
f) Land system with >15% of its area covered by lakes >50 acres in size.
g) Land system bordering the St. Lawrence.
h) Land system with >5% of its area covered by rivers >50 feet wide.

SHORELINE PLAN
Regular, Irregular or Very Irregular.

VALLEY SHAPE
Sinuous, Meandering or Anastomosing.

BEACH SLOPE
Gentle, Moderate or Steep.

PRESENCE OF RAPIDS
None, Few or Many.

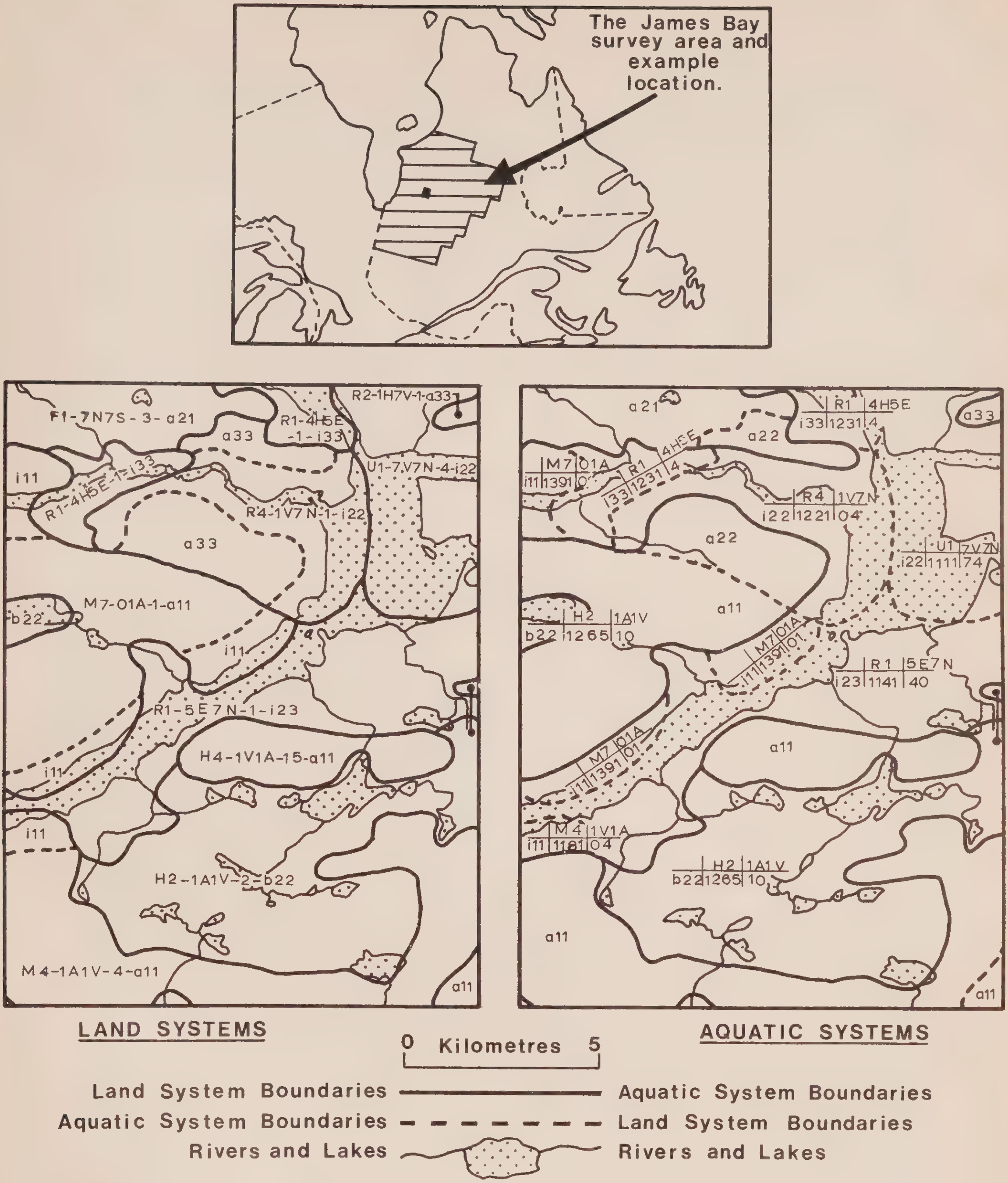
SLOPE OF THE BANKS
Primary: Gentle, Moderate or Abrupt
Secondary: Gentle, Moderate or Abrupt
These combine into 9 classes.

DRAINAGE SYSTEM OF LAKES
Open, Restricted or Closed.
Deep, Shallow or Wetland.

DRAINAGE SYSTEM OF RIVERS
Open, Deep or Shallow.

SURFICIAL GEOLOGY
A detailed classification of 38 types as used for dry-land systems. See Annexe 7, Jurdant et al, 1972.

Table 2: The Classification of Aquatic Ecosystems, SEER (1972).



THE PORTRAYAL OF LAND AND AQUATIC SYSTEMS IN THE ECOLOGICAL LAND SURVEY OF THE JAMES BAY TERRITORY

Figure 5

Table 3: The Classification of Aquatic Ecosystems, SEER (1976).

CATEGORY OF AQUATIC ECOSYSTEMS

a) 5% covered by water surfaces.
b) 5%-15% covered by lakes < 250 ha.
c) >15% covered by lakes <250 ha.
f) areas bordering lakes >250 ha. and <500 ha.
g) areas bordering lakes >500 ha. and <1000 ha.
h) areas bordering rivers.
i) areas bordering large rivers.
j) areas bordering James Bay.
m) areas bordering large rivers subject to tides.
n) areas bordering lakes >1000 ha. and <2500 ha.
r) areas bordering lakes >2500 ha.

ABUNDANCE OF STREAMS
Absent or Very Few, Few, Moderate Number, Many, Abundant.

ABUNDANCE OF WETLAND
Absent or Very Few, Few, Moderate Number, Many, Abundant.

LAKES: PERIMETER SHAPE
Regular, Irregular, Very Irregular

LAKES: BEACH SLOPE
Gentle, Moderate, Abrupt.

RIVERS: VALLEY PATTERN
Sinuous, Meandering, Anastomosing.

RIVERS: PRESENCE OF RAPIDS
None, Few, Many.

BACKSHORE OR VALLEY-SIDE SLOPES
Primary: Gentle, Moderate or Abrupt
Secondary: Gentle, Moderate or Abrupt
These combine into 9 classes.

DRAINAGE SYSTEM AND DEPTH
Open, Restricted or Closed.
Deep, Not Deep or Wetland.

MAP LEGEND DATA	
Channel Reach	1 Fish Species, e.g. Coho Salmon, Lake Trout, Unknown Species.
	2 Long Profile. Convex, Regular, Stepped, Concave.
	3 Channel Slope. Graduated to 1% in tenths, above 1% to nearest %.
	4 Cross Section. Confined, Confined in 1-2yr. flood plain, Unconfined.
	5 Substrate. 0-2mm, 2-100mm, >100mm, rock.
Headwater Tributary Classes	>5% gradient, confined; >5%, unconfined; <5% gradient.
Lake Symbols	1 Depth. 0-6m. maximum, 6-30m. maximum, >30m. maximum.
	2 Opacity. Secchi Depth in metres.
	3 Percent Littoral Area (0-6m. depth) to the nearest 10%.
REACH DATA IN ASSOCIATED TABLES AND FIGURES	
Debris	1 Present. None, Some, Much.
	2 In Transit.
Bank Vegetation	1 Vegetation Classes. Coniferous, Deciduous, Shrub, Grass, Bare.
	2 Channel Crown Closure.
	3 Bank Overhang Closure (lower story).
Bank Material and Stability	% active slumping, dominant material texture.
Hydraulic Parameters	1 Flow Estimates.
	2 Cross Section Width - Channel and Wetted at the time of survey.
	3 Floodplain Width.
	4 Depth.
	5 Velocity.
	6 Flood or Side Channels. None, Some, Numerous.
	7 Pools.
	8 Flow Character. Placid, Swirling, Rolling, Broken, Tumbling.
Channel Form	1 Banks. % Sloping or Level, % Vertical or Overhung.
	2 Channel Pattern. Single or Multiple Thread Form. Straight, Irregular, Meandering. Stability. Braided, Bars, Islands.
	3 Entrenchment. None, Moderate, Deep.

Table 4: The British Columbia Environment and Land Use Committee Aquatic System Mapping Legend (1976).

water body classification for purposes of ecological land survey. Instead it is more appropriate to follow a common methodology and pool of experience in order to establish an optimum classification for any given area.

The British Columbia classification is summarized in Table 4 (after ELUC, 1976). Critical to this classification is the recognition of the "reach" as a mapping unit. A reach is *"defined as a section of channel with relatively homogenous properties"* (ELUC, 1975, p.2). Furthermore *"a reach symbol applies down or up to the next tributary junction unless both an upper and lower reach break exists in which case the symbol applies to the stream segment so defined"* (ELUC, 1976, p.2). A stream reach is therefore always equal to or less than a stream link in the geomorphic sense. The intent is to apply this classification to a fairly detailed level of mapping, using point and transect field data sources (ELUC, 1975). This scale and reach definition is equivalent to the land type level of mapping mentioned earlier (Sub-Comm. Bio-phys. Land Classif., 1969, p.6), in contrast to the SEER methodology which maps land systems, districts and regions. Since the British Columbia classification relies most heavily on morphologic data at the land type level, and since the SEER classification does likewise for land systems, then the two experiences complement, rather than compete with, one another.

ECOCLASS: UNITED STATES DEPARTMENT OF AGRICULTURE (USDA)

In the early 1970's the United States Department of Agriculture Forest Service established an Ecosystem Task Force for the purpose of developing an ecosystem classification for the United States Pacific Northwest (USDA, 1973). This Task Force eventually developed a philosophy for the hierarchical classification of landscape similar to the Canadian "bio-physical" approach. In fact, both philosophies derive from the Australian methodology of Christian and Stewart (1968). Ecoclass recognizes two distinct hierarchies. The first is based on the mapping of vegetation and habitat at various levels of scale and commonality. The second hierarchy, one of Ecological Water Units, is a function of water bodies and their morphology, quality and flow system (Table 5).

Ecoclass is intended, therefore, for the mapping of land and water systems in the Western Cordillera of the United States. Information is stored in text form rather than in a map legend. Thus despite the similarity of terrain, the Ecoclass method differs from that of British Columbia's Aquatic System method: the latter focusses on detailed maps and related legends.

There is a further divergence of approach. In the ELUC system we are shown a method of

Vegetation System	Land System	Aquatic System	Bases of Aquatic Systems	Examples
Formation	Province Section	Order	Salinity	Oceans, Freshwater, Estuaries.
Region		Class	Physical Character	Streams, Marshes, Lakes, etc.
	Subsection			
Series		Family	Temperature	Cold Streams, Temperate Lakes
	Landtype Association			
Habitat		Aquatic Type Association	Drainage Basin	Mountain Streams, Kettle Lakes
	Landtype			
Community		Aquatic Type	Homogeneity	Reach of similar meanders, Lake or part of a large lake.
	Land Unit			
Ecological Land Units		Ecological Water Units		

Table 5: Ecoclass, USDA (1973).

detailed aquatic site description, whereas with Ecoclass we are shown how to integrate upwards into more general taxonomic units of land and water. In Ecoclass, land and water units are recognized separately, and can later be amalgamated into various levels within a systems hierarchy (Table 5). Although using a different format, this is similar to the SEER approach, wherein aquatic systems are given boundaries different from land systems, amalgamation occurring mainly during the secondary process of interpretation.

ONTARIO: HILLS

During the last three decades, G. Angus Hills has been associated with the emergence in Canada of the ecosystem concept in land use planning. Hills recognized that ecosystems are constructed of living and non-living elements (Hills, 1961; Hills, Love and Lacate, 1970). He adds that *"the non-living parts of an ecosystem are collectively known as 'physiography' which consists of both landform and climate"* and that *"because of their relative stability, landform features are used to classify ecosystems"* (Ibid, p.7). In Hills view the word "landform" connotes materials as well as morphology, since both are intimately related in determining habitats, or site conditions, for the biotic environment.

Akin to the land/water classification schemes already discussed in this paper, Hills established a hierarchy of sites according to relative size and unifying criteria (Hills, Love and Lacate, 1970, p.45-47). Site regions, areas of similar climate, are subdivided into landtypes of soil texture, mineralogy and depth. Landtypes are further differentiated into physiographic site types on the basis of soil moisture regime, detailed variations of soil depth, and local climate. Although there is an additional division into site phases, according to features such as steepness of slope and stoniness, Hills stresses that *"the physiographic site type is a basic physiographic unit in plant ecology, since the control exercised by this complex of factors results in a narrow and identifiable range in natural vegetation succession and production. Thus, upon each physiographic site type a series of ecosystems develops, according to the natural controls of plant succession, and to the human control of crop production"* (Ibid, p.46).

In principle Hills argues that limnic ecosystems are as much a function of surrounding land as they are of their own morphometry (Hills, Love and Lacate, 1970, p.15), citing for example the rôle of soils in nutrient supply and basin relief in wind circulation. Unfortunately this recognition does not carry over to the establishment of land and water classifications and mapping units. In Hills' suggestions for water body mapping, only a lake morphometry classification is outlined (Ibid, p.57-59; Table 6 in this paper). Futhermore, the eventual implementation of Hills' ideas in the Ontario Land Inventory (OLI) does not incorporate water information (OLI, 1975). Thus although in Ontario there is land data from which experts can infer a lake's natural condition, there is no single, integrated information base for the non-specialist planner or manager, nor are land units defined on the basis of water content as an integral component, such as in the SEER methodology, nor is there any information on river systems. For lake and stream information, the user must instead go to separate sources, such as the Ontario Lake Survey Program (Dodge, 1976).

Perhaps these absences stem from Hills' earlier definition of an *"aqueous physiographic site"*, as opposed to a terrestrial one, as *"the physical, non-living portion of an aquatic productivity unit. Since a lake, plus the organisms which it supports, constitute a single productivity unit (ecosystem), a lake-type is an example of such a physiographic unit"* (Hills, 1961, p.42). While this distinction between land and water sites is easy to apply, planning and management manipulations of the natural environment require instead that we recognize "control" systems, that is to say the functioning extent of an ecosystem, and that we select the appropriate magnitude of control system, be it regional, district or otherwise, for purposes of resource development and monitoring.

THE CANADA LAND INVENTORY (CLI)

The Canada Land Inventory is a comprehensive survey of land capability and use designed to provide a basis for resource and land use planning. Although the CLI does not use an ecological approach to classifying units of land, it is included here for comparison because it is nevertheless a major resource survey, and also includes a certain amount of water information. The CLI includes evaluations of land capability for agriculture, forestry, ungulates, waterfowl, sportfish and recreation, and also a mapping of present land use. The inventory was intended to cover settled portions of rural Canada and adjoining areas which affect the income and employment opportunities of rural residents (CLI, 1970).

Like the land surveys discussed above, the Canada Land Inventory is not restricted to

Table 6: Morphometric Classes of Water Units, Hills, Love and Lacate (1970).

TYPE OF CHARACTERISTIC WATER BODY

Absolutely Small:	Less than 25 sq. ft.
Extremely Small :	Less than 5 acres.
Small :	5 acres to 640 acres.
Relatively Small:	1 sq. ml. to 16 sq. mls.
Moderately Large:	16 sq. mls. to 50 sq. mls.
Large :	50 sq. mls. to 450 sq. mls.
Very Large :	450 sq. mls. to 5,000 sq. mls.
Great :	Over 5,000 sq. mls.

CLASSES OF OPEN WATER

Fully Restricted:	Dominant	Length	of	Fetch	less than 2 miles.
Greatly Restricted:	"	"	"	"	2 to 4 miles.
Relatively Restricted:	"	"	"	"	4 to 7 miles.
Slightly Open:	"	"	"	"	4 to 7 miles.
	Subdominant	"	"	"	7 to 50 miles.
Moderately Open:	Dominant	"	"	"	7 to 50 miles.
Open:	"	"	"	"	7 to 50 miles.
	Subdominant	"	"	"	over 50 miles.
Very Open:	Dominant	"	"	"	over 50 miles.

IRREGULARITY OF SHORELINE

Absent, Regular, Slightly Irregular, Moderately Irregular, Very Irregular.

INSULOSITY: PERCENTAGE OF WATER BODY OCCUPIED

0%-0.1%, 0.1% to 3%, 3% to 10%, 10% to 20%, 20% to 40%, >40%.

INSULOSITY: DOMINANT SIZE OF ISLANDS

Variable, Small, Large.

---

certain land features, and is the most extensive inventory of its kind ever conducted in Canada. The CLI ranks land according to its capability to support a given use of land, irrespective of whether or not that use of the land is taking place. To each unit of land so evaluated is added a modifying symbol which describes a certain attribute or limitation for the assumed usage. Those modifiers that relate to water are listed in Table 7. The Waterfowl and Sportfish Capability Classifications are essentially concerned with water bodies, and several modifiers are used which could apply to other uses. Agriculture and Forestry may be affected by extremes of soil moisture and by erosion. Surprisingly, the Present Land Use Classification does not cover the *use* of water bodies; instead it merely distinguishes between open water and swamp, marsh and bog. In contrast the aquatic modifiers for recreational capability are quite numerous, perhaps reflecting the amount and variety of man's indirect use of aquatic resources. In an era of increasing leisure time, these recreative uses are fast becoming as important as traditional, productive uses.

In contrast to the ecological land classifications discussed elsewhere in this chapter, the CLI does not describe water bodies in their own right, nor does it establish a spatial hierarchy of water units. Even so, it does enumerate some important considerations for describing water, and it does demonstrate the reality of large area natural resource inventories for planning and management.

OTHER CANADIAN LAND SURVEYS

So far I have examined the water classifications of a number of land surveys. They have been selected on the basis of their contribution to Canadian methodology and experience in the matter of northern or remote land mapping. Of these classifications, those of the Canada Land Inventory, the Ontario Land Inventory and of the Service des Etudes Ecologiques Régionales have been put into effect for extensive land surveys (Figure 1). Several other land mapping projects have been completed or are in progress, most of which are based upon the Guidelines for Bio-physical Land Classification already outlined in this paper. These projects are in the various national parks, the Yukon, the Mackenzie valley, the Boothia Peninsula and Melville Island. In all

Table 7: Water Features of the Canada Land Inventory.

CAPABILITY	SYMBOL	DESCRIPTION OF MODIFIER
Present Land Use	Z	Water
	M	Wetland (Swamp, Marsh or Bog)
Agriculture	I	Inundation
	W	Excess Water (e.g. from poor drainage)
Forestry	-	- - - -
Ungulates	I	Inundation
Waterfowl	B	Free Flowing Water
	G	Landform (e.g. poor interspersion of marshes)
	I	Inundation
	J	Reduced Marsh Edge
	Z	Water Depth (excessively deep or shallow)
Sportfish	D	Depth, Littoral Development or Basin Shape
	F	Flow, Water Level Variations, or Flushing Rate
	L	Light Penetration Limitation
	N	Nutrient Limitation
	O	Oxygen Limitation
Recreation	A	Access for Sportfish Angling or Viewing
	B	Family Beaches
	C	Access for Canoeing Waters
	D	Shoreland for Swimming or Boating
	F	Waterfall or Rapids
	G	Glacier Viewing
	K	Shoreland or Upland for Camping
	M	Frequent Small Water Bodies
	Q	Variety of Land-Water Relationships
	T	Thermal Springs
	U	Deep Water Shorelands
	W	Access for Wetland Wildlife Viewing
	Y	Access for Shoreland Boating

of these exercises the water bodies are mapped as holes in the land, as if the water itself were not present. For example, in describing an ecological land survey of L'Anse aux Meadows National Historic Park, Gimbarzevsky (1977) restricts water information to the sizes of lakes and ponds.

These mapping projects are reviewed collectively in the 1976 Proceedings of the Canada Committee on Ecological Land Classification (Thie and Ironside, 1977). One ecological mapping project which is not included is that of the Peace-Athabasca Delta (Dirschl et al, 1974). Certain water features are discriminated, such as Flowing Water versus Standing Water, the presence or absence of emergent vegetation, and the degree to which lakes have free or restricted drainage. Perhaps this is because of a primary concern with a deltaic landscape, and because of the relatively large scale of mapping (1:37,000), wherein individual landforms are readily discerned and mapped.

SUMMARY

The preceeding review of certain land surveys shows how various and wide-ranging are the water features, water data and methods of integration of terrestrial and aquatic resource mapping. Later in this paper will be reviewed some classifications and surveys of specific features. From this will be proposed an approach to integrated land/water mapping, and appropriate types of data. At this point, however, it is sufficient to draw together certain prerequisite principles for integrated land and water survey.

These principles are that a water classification should be (1) meaningful, (2) simple, (3) unified with land data and (4) flexible. In being meaningful, a classification should have both ecological and hydrological significance, and be able to recognize a wide range of scales and also short and long-term dynamic events. By simplicity is meant that data should be collected by simple techniques,

and quantified according to simple, unambiguous scales or classes of data. To achieve these goals, the parameters should describe those stable environmental features which nevertheless play a significant role in controlling dynamic processes. This is essential to an inventory which can only feasibly and economically rely upon remote sensing and field checking at one date of one season. A unified system must recognize the interconnectedness of land and water features. For example, a lake or lakes should be mapped as part of a land-lake system which encompasses its terrestrial environs. Finally data storage, perhaps by computer, should be designed so that a variety of interpretations can be quickly produced, dependent upon the user's needs. For example, a lake "region" for recreative and sportfish purposes may be bounded differently to a river "region" such as a major drainage basin.

Thus we now have several concepts which the landscape classifier must bring to an area to successfully map its resources. Before concluding upon a mapping philosophy and methodology, however, we must also examine how the natural environment is organized, and how that organization can interface with a resource inventory.

Chapter Three

THE STRUCTURE OF THE ENVIRONMENT

I live on Earth at present
and don't know what I am
I know that I am not a category
I am not a thing - a noun
I seem to be a verb,
an evolutionary process -
an integral function of the universe.

Buckminster Fuller

LAND SYSTEMS

That the landscape is made up of systems of interdependent objects and processes is now universally accepted. Furthermore, it is a tenet of ecological land survey that these systems can be given a finite extent, within which the environment acts in a holistic manner. Unfortunately there seems to be some confusion over what constitutes a "system", particularly in the use of the term "land system". Landscape units are often identified by *"recurring patterns"* of objects at various specified or implied map scales (e.g. Christian and Stewart, 1968; Sub-Comm. Biophys. Land Classif., 1969, p.5). Since pattern recognition is subject to disciplinary, operational and scale biases, being largely a subjective skill, it is possible for different investigators to arrive at differing divisions of land. To these perceptual problems are added quasi-statistical ones when a "recurring" pattern is sought as the basis for landscape mapping. Another problem is that a pattern or recurring pattern of landscape characteristics is a morphologic attribute which may or may not be the result of present-day environmental processes. For these reasons, and since water is an especially dynamic phenomenon, the following basis for an integrated philosophy of land/water survey is proposed. The ideas themselves are not original to this author, being derived from General Systems theory in the earth sciences (e.g. Chorley and Kennedy, 1971) and in the life sciences (e.g. Bertalanffy, 1960). What is new are the lessons which show us the scope and limitations of a given approach to ecological land survey.

GENERAL SYSTEMS

Systems

A *system* is an association of phenomena having at least one property in common. The recognition of the spatial and dynamic properties of systems aids in understanding, and therefore managing, the real world. For example, once the limits of a system have been defined, the extent of environmental impacts is easily forecast. Several kinds of systems exist, but only four are relevant to ecological land survey.

Morphologic Systems

A *morphologic system* is a set of similar objects. Their similarities may be of shape, size, colour, temperature, or of any other descriptive property. The members of a morphologic system may be contiguous, as in the case of polygons making patterned ground, or apart, such as a group of talus cones, or only partially touching, as are the streams of a drainage pattern. In Canadian practice land systems as defined are morphologic systems, since they are supposedly characterized by a recurrence of pattern. These systems are extremely useful to the reconnaissance of land resources, since the use of morphologic systems obviates the collection of detailed repetitive data. Nevertheless they have limits in application, since their components are not always directly connected in any dynamic way, so that environmental impacts or natural hazards need not coincide with the spatial boundaries of units based on morphologic properties alone.

Process Systems

In a *process system* there are transfers of energy or mass or both. Examples are photosynthesis, the hydrologic cycle, debris transport, agriculture and the diffusion of culture. A process system is therefore an abstract entity in which some thing or property changes position or state over a certain period.

Process-Response Systems

Processes involve losses, gains, and changes to the objects connected with those processes. Although at any moment and place a river can maintain a steady state of water flow and

sediment movement, it will eventually erode or deposit large amounts of material over wide areas. River channels and drainage basins are therefore examples of *process-response systems*. A process-response system is an object or group of objects which respond and change in concert to one or more processes. Soil formation and plant growth are examples.

Control Systems

It is almost trite to say that for process-response systems to function, their objects and processes must first be assembled. This is achieved by *control systems*, which in natural environments are exemplified by bed-rock geology, tectonic events, regional climate, paleolandforms and, nowadays, man. In an analogy to mathematics, control systems provide the independent variables, while morphological, process and process-response systems provide the dependent variables.

DIVISIONAL AND FUNCTIONAL HIERARCHIES

Divisional Hierarchies

There are at least two important ways of organizing systems on the earth's surface. The first is by a *divisional hierarchy* such as represented in Figure 6, whereby land can be divided into various levels of pattern, pattern of patterns, and so on. Divisional hierarchies display the same inherent advantages and disadvantages as morphologic systems, for in essence that is all they are. Note that in Figure 6, for example, several trees may be grouped into small morphologic systems, stands, at level one. To integrate them into a higher level, however, these systems must themselves be amassed into larger "objects". Only then can morphologic systems be correctly defined at level two. Thus to construct and interpret maps based on morphologic systems at various levels requires more skill and intuition than meets the eye, or as implied by the definition of land systems proposed by the Sub-Committee on Bio-physical Land Classification (1969).

Figure 6 also demonstrates a problem of strictly divisional hierarchies, whereby the objects grouped may or may not have any cause-and-effect relationships in common. If, for example, the objects A, B and C represent headwater streams at level one, and at level two the sets of streams flow outward from a central water divide, then the larger, encompassing morphologic system becomes meaningless for any properties of flow and drainage. Therefore divisional hierarchies, being based on morphologic systems, contain the risk of producing divisions of land which are of little relevence to certain processes.

Functional Hierarchies

An alternate method of integration is to employ a *functional hierarchy*, as illustrated by Figure 7. Whereas divisional hierarchies build up from small units, functional hierarchies are organized from cause to effect. In this model, control systems decide upon, or control, process systems which interact with the objects of morphologic systems to produce process-response systems. For example, climate controls runoff which in turn interacts with hillslopes to produce stream channels. Eventually the objects themselves change to the extent that they may modify processes and controls; this is called *feedback*.

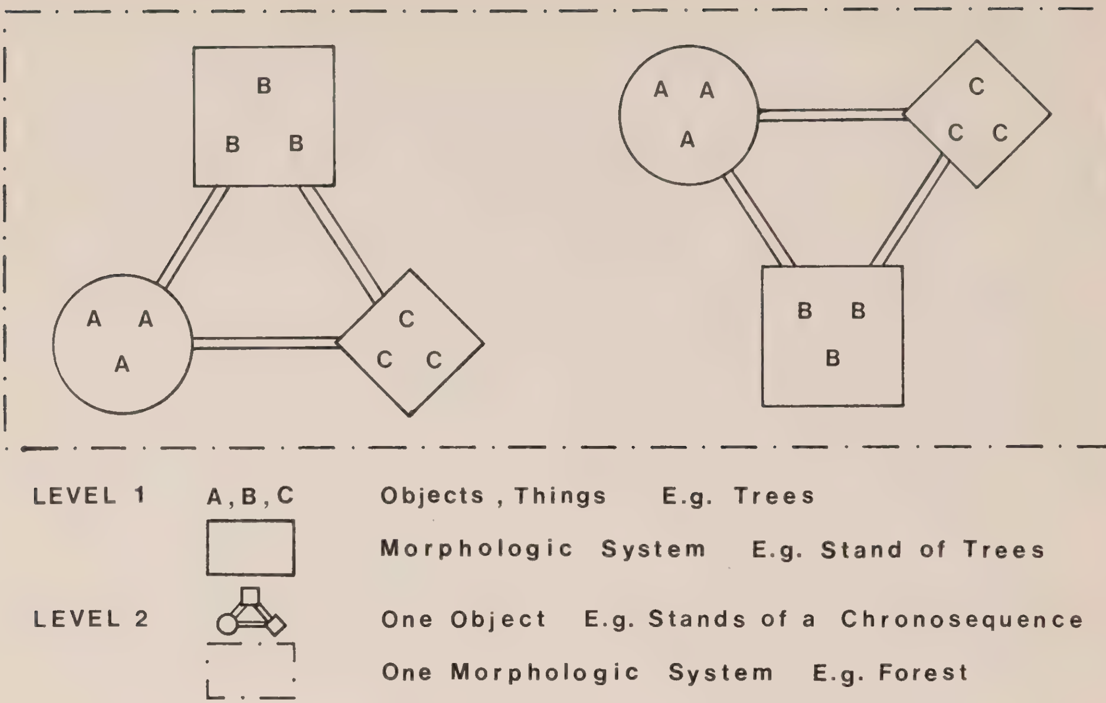
The model of functional hierarchies is powerful for a number of reasons. For one, connections between systems can be arranged in a number of ways, such as two controls affecting nine objects (Figure 7) or some objects being able to influence controls through the feedback process just mentioned. For example, relief and climate may dictate the nature of mountain glaciers, but a glacier itself has some control over climate. Figure 7 symbolizes these kinds of relationships in a two-dimensional way. Multiple controls and overlapping and disparted morphologic systems could be represented in a multidimensional model of a functional hierarchy.

A Systems Definition for Land

Recognition of the various direct and indirect relations and hierarchies of systems now permits a broader definition of a system of land than merely one of a recurring pattern of landscape elements. I suggest the following definition:

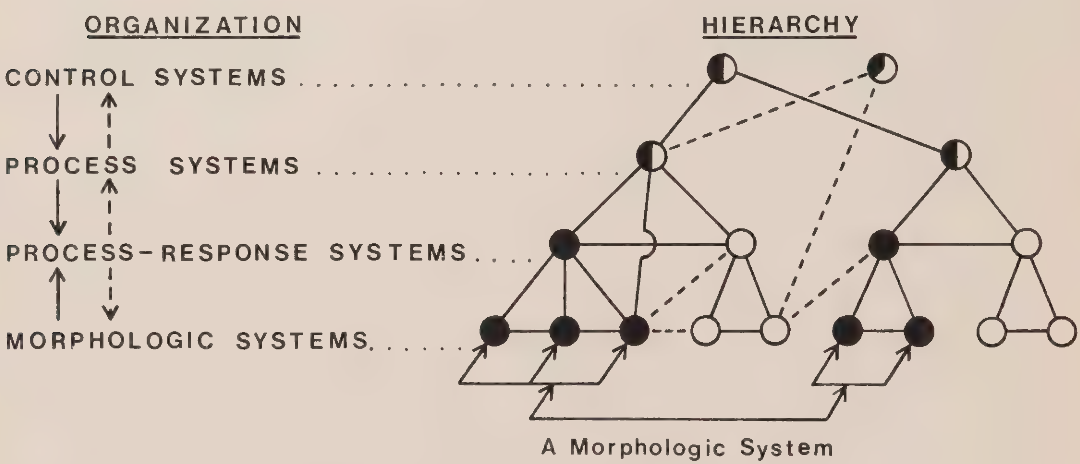
A Land System is a tract of land that would respond as a system to an externally applied event, or whose components would respond in a similar way to a uniformally applied event.

The word "event" is used in a wide sense. An event could be a flood, a climatic change, a forest fire, a clearing of forest for agriculture, annual freeze-up on a lake or river, the passage of a large number of animals (including people!), or any other sporadic, repetitive or unique stimulus. Defined this way, events and land systems can occur at any scale, from the global to the microscopic. It is a definition for the way we should look at landscape, and hence how we should map it and manipulate it. The last chapter of this paper describes how water can be integrated



TWO LEVELS OF MORPHOLOGIC SYSTEM IN A DIVISIONAL HIERARCHY

Figure 6



FUNCTIONAL HIERARCHIES

Figure 7

with ecological land survey using this attitude to mapping, and also discusses alternate terminology to avoid confusion between this definition of land system, which is scale-independent, and that of the Sub-Committee on Bio-physical Land Classification (1969) and others which is tied to a specified hierarchic level and map scale.

The preceding definition of a system of land is adequately illustrated by the definition of *"water units"* as proposed by Hills, Love and Lacate (1970, p.57). *A water unit is an area of water . . . having a pattern of physiographic sites which provides a convenient unit for use-considerations such as fisheries and water-based recreation . . . A water unit may or may not coincide with a water body only if there are no major differences in use potential from one portion to another . . . A water unit is not exclusively water . . . (small) water bodies. . . are part of the land unit in which they are located"* (Idem).

Drainage basins also illustrate how this general definition of a land system transcends the morphological to emphasize processes and responses to them. For studies of runoff response, water use and impact, the drainage divides provide clear spatial boundaries. In contrast morphologic system boundaries would draw together all headwaters into one group, all meander plains into another, and so on (Figure 8).

TIME AND CHANGE

So far land systems have been considered only as they relate to a uniform set of controls. In hypothetical cases, such as constant climate, tectonic stability or social stagnation, the systems of processes and of objects can be represented as axes in two dimensions, with a resultant vector indicating a process-response system (Figure 9). Control systems can now be represented by an orthogonal dimension. Climatic change, earthquakes, deglaciation, rural depopulation, or whatever, can be expressed pictorially by moving the complete plane of morphologic and process systems along the control axis, each position of the plane corresponding to one set of control systems (Figure 10).

Since, in the long term, causality operates from controls down to objects, via the mechanisms of process-response systems, these systems and their objects will take longer to change than the controls and processes themselves. This effect is further enhanced because physical realities require more time to change than do abstractions, such as when the channels and valleys of a drainage system resist change more strongly than the runoff regime which controls flow in the channels.

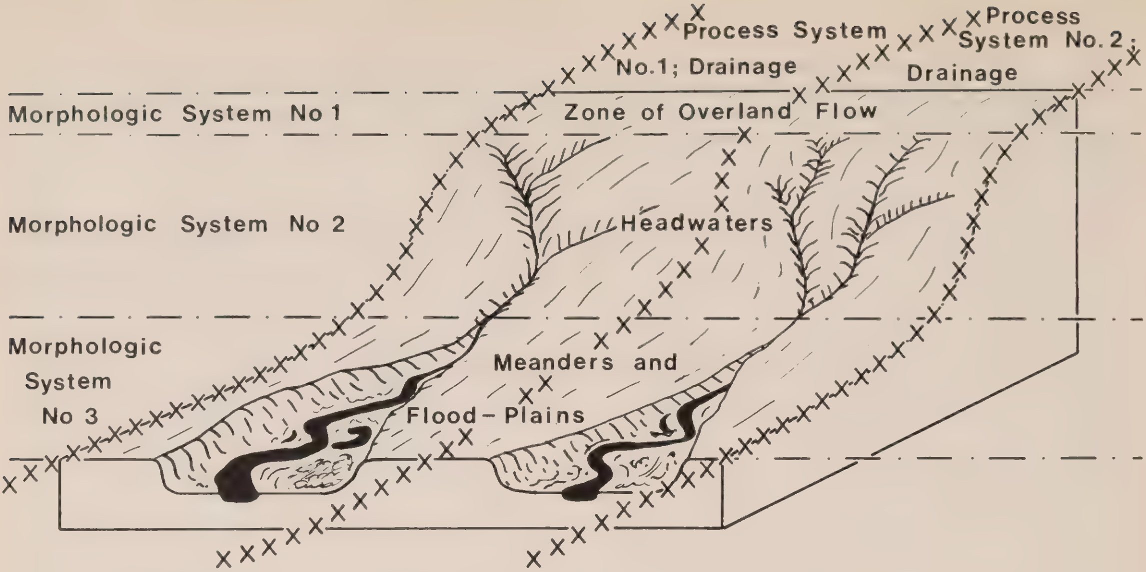
Because of this resistance to change, the physical features of a landscape do not always keep pace with changes in control and process systems. The result is a presence of relict features, as exemplified by decaying permafrost, end moraines, and stabilized dunes. These artifacts of nature are sometimes called "historical hangovers" (Chorley, 1964). As illustrated by Figure 10 and in nature, more than one morphologic system can exist independently within the same area and time, depending upon the recency of the change in controls, the intensity of the new controls, and the magnitude and stability of the pre-existing morphologic system or systems.

While mapping the environment, it is therefore important to recognize those objects and processes which have contemporary ecological significance, and to avoid delineating units of land on the basis of hangovers. For water bodies this means delineating units of land on the basis of lake systems or drainage basins even when highly diverse landforms and vegetation are encountered, rather than attempting a genetic classification. This same argument also applies to the critique of "recurrent pattern" as a basis of land mapping. Perhaps the phrase should have been modified to "recurrent pattern of processes".

SUMMARY

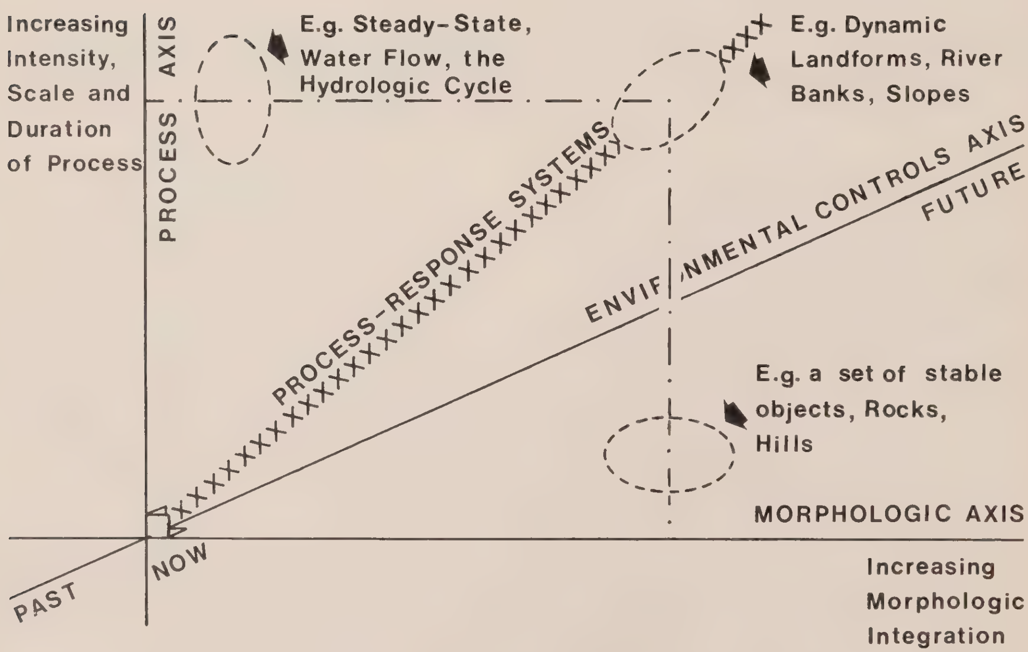
Not all of the present-day features of landscape can be used to define ecologically significant land units, otherwise a lake district can be very different from, say, vegetation or stream districts. An ecological land survey must detect those features of current significance to processes and construct mapping units accordingly. Where large groups of "hungover" features occur, such as in districts of lakes, then regional integration of those features may have to avoid the use of, e.g., lake genesis and shape, and instead classify areas by flow, sediments and life stage, etc..

At large scales, such as the level of most process-response systems, there are none of the problems of creating divisional hierarchies based on morphologic systems. Detailed ecological inventories can therefore proceed, using the kind of definition of land systems proposed herein. Regional integration for small scale maps must, however, be treated with care, using process and control criteria which are significant at that wide scale.



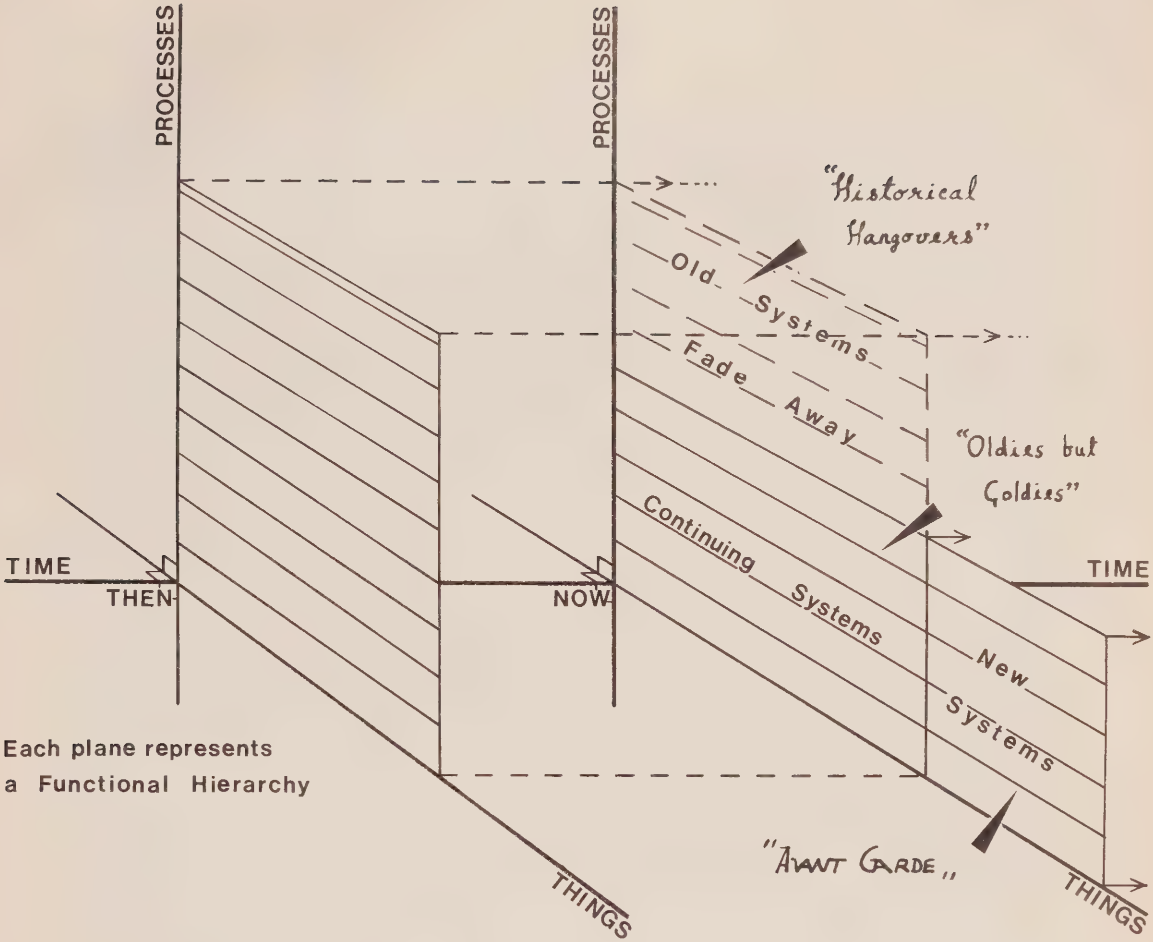
A COMPARISON OF MORPHOLOGIC AND PROCESS SYSTEMS

Figure 8



INTERACTIONS OF MORPHOLOGIC AND PROCESS SYSTEMS

Figure 9



FUNCTIONAL HIERARCHIES, TIME AND CHANGE

Figure 10

Chapter Four

LAKE CLASSIFICATION AND SURVEY

Lake, mere, lagoon, land-locked water, lock, lough, linn, inland sea, ox-bow, bayou, broad, standing water, dead water, sheet of water, mud flat, wash, marsh, pool, tarn, pond, piscina, aquarium, reservoir, basin, cistern, sump, cesspool, sewer, sink, ditch, water-hole, puddle, sough, splash, wallow, Irish bridge (sic).

Roget's Thesaurus

THE ECOLOGICAL SIGNIFICANCE OF LAKES

A glance at a map of Canada reveals a large number of lakes, including the majority of the world's great lakes. Satellite and aerial photographs enlarge the picture to show that many parts of Canada's landscapes are in fact dominated by lakes (Figure 11) of many kinds (Figure 12).

"Lakes are part of, indeed they essentially form, the landscape from Newfoundland to British Columbia. Even in the most populous province, there are said to be 250,000 lakes . . ." (Bruce, 1974, p.505). Manitoba boasts of 100,000. There are possibly one to one and a half million lakes in Canada, most still un-named. By their sheer number and area, therefore, lakes are a considerable natural resource. Furthermore, many present and planned uses of land tend to focus on or around lakes. Remote lakes have a habit of becoming accessible as development of mines, recreation, exploration, winter roads, logging and defence works continues.

To plan for the optimum or multiple use of land or lakes, and to minimize pre-emptive use, it is necessary to consider lakes as a part of the landscape system (Dworsky, 1970). Lakes must be evaluated in terms of properties such as size and water budget, the through-flow of water, sedimentation, trophic status and stage of evolution, and the nature and rate of shoreline changes. All of these processes have deep significance for the quality of the environment, its aesthetics, public access, destruction of wildlife, mercury contamination of fish, and so forth. As discussed earlier, lakes are an integral part of the land (territoire): for planning and management purposes an equally integrated data base is therefore essential.

LAKE CLASSIFICATION

Introduction

To the neophyte, limnology appears to be studded with a constellation of classifications. Consequently this review attempts only to present and compare a limited cross-section of lake classifications and to extract some prevailing themes and suggestions for ecological land/water classification. This selection is based as much upon the guidance of personal communications as it is upon the literature. The reader should consult the acknowledgements for these sources.

If the plethora of classifications were simply related to different detectable properties or to regional variations in significant limnic attributes, then a review would be lengthy but at least not intrinsically difficult. As in most other sciences, however, limnologists do not always concur about the nature of classification. Consider these two contrasting statements.

"In reality . . . the various definitions (of trophism) all are (sic) essentially the same since high nutrient fluxes result in higher plant and animal production and decreased water quality" (Lee, 1970, p.2).

"There can be no single universally satisfactory method of classifying lakes and estimating relative trophy in natural ecosystems . . . Descriptive classification techniques, limnetic primary production estimates, and biomass estimates all measure essentially different qualities . . ." (Larson, et al 1973, p.15).

Conflict of opinion also exists over more specific issues. In analyzing the factors governing the productivity of lakes and reservoirs, Brylinsky and Mann (1973) found that solar energy input has a greater influence on production per unit area than variables related to nutrient concentration. Other authors feel that productivity should relate to units of volume and hence depth (Horne and Newbold, 1975) and vertical mixing (Richardson, 1975). As a basis for trophic classification, even the idea of nutrient concentration is in jeopardy, as indicated by Vollenweider (1971), Dillon (1975) and Schindler (1971), who stress nutrient flux as being of greater importance to aquatic productivity than nutrient status at any given moment.

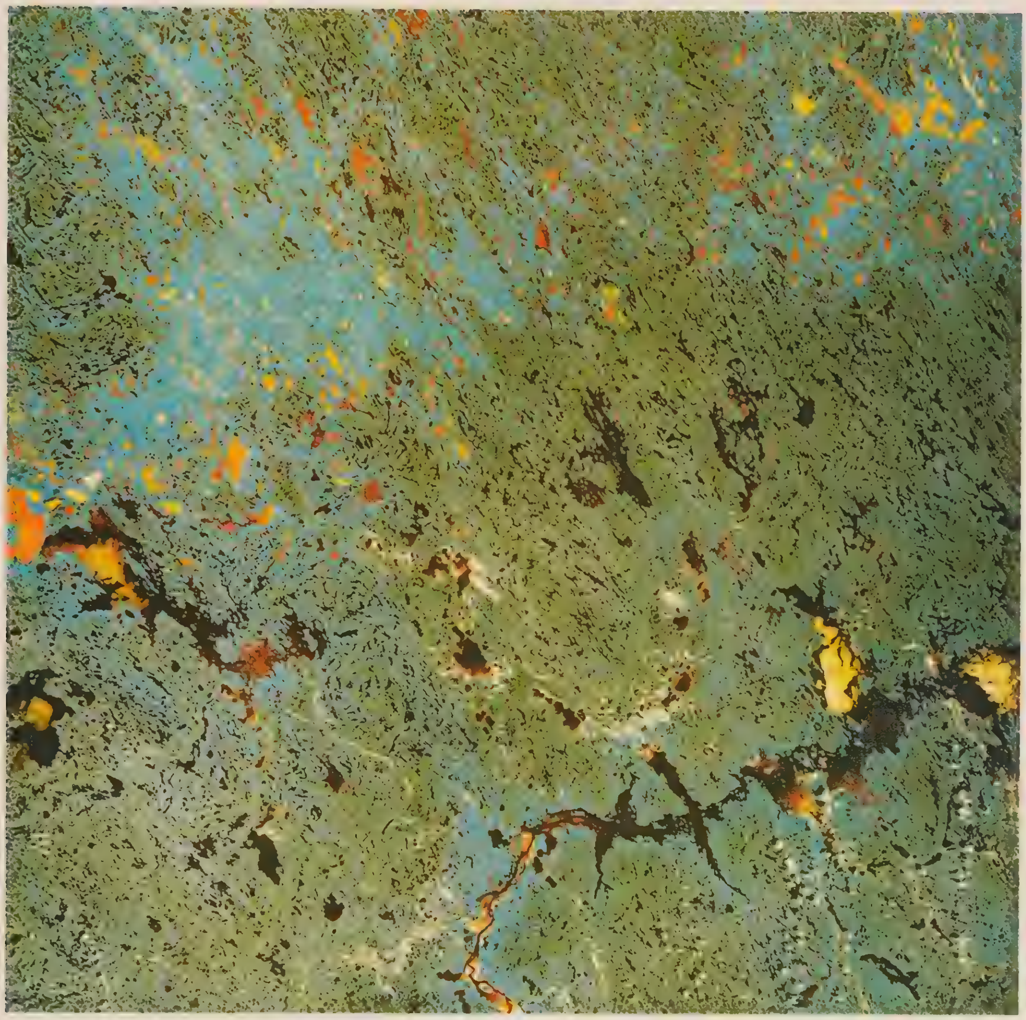


Figure 11: The Multitude of Canadian Lakes; an example from the Garry Lake area, northwest Keewatin. Landsat, 13 July 1974, composite of bands 5, 6 and 7, approximate scale 1:1,000,000.

Figure 12: The Variety of Canadian Lakes

In view of the diverse nature of lakes, the ever-changing nature of land and water uses, and the dynamic state of the science of limnology, it is therefore unwise to construct a single, universal scale for the classification of lakes. The difficulty of lake classification, however, runs deeper. Whereas limnology means the study of lakes, in practice only limited aspects of lakes seem to be covered by the discipline. Recreative use, landscape aesthetics, sport fishing, water supply, hydrologic functions, shoreline properties and processes, and microclimatic processes tend to be scattered through other disciplines such as planning, forestry, geomorphology, meteorology and engineering. In view of this broadcast of knowledge, the best lake classification that a land survey should attempt is to collect data for a number of variables which can be manipulated collectively to describe a lake for foreseeable purposes.

Environmental Lake Classifications

Among the ecological land classification and the limnological writings already cited here there is a wide spectrum of approaches to lake description and characterization. Like optical spectra, these approaches concentrate into well defined "bands". The ecological land classifications tend to focus on descriptive properties of lake morphometry and terrestrial environments. These are stable properties which can be measured on aerial photographs. In this category are also a few limnologic studies, such as those by Rawson (1955, 1960) who emphasized depth as a dominant factor, and by Conroy (1971) who found that depth and the presence or absence of limestone in a lake's basin control biological activity in certain Precambrian Shield lakes.

Functional Lake Classifications

Most of the limnologic classifications of lakes tend to be functional, selecting variables which depict dynamic properties such as water budget and quality, and which usually require a time-series of on-site measurements. Limnologists are currently stressing nutrient flux (e.g. Dillon, 1975) or total nutrient mass (e.g. Ryder et al, 1974). Carlson (1977) has attempted to reduce several measures of lake trophism, namely secchi transparency, chlorophyll 'a' and total phosphorous, to a common Trophic State Index. All of these classifications have biological productivity as a main concern. In comparison, Bogoslovsky (1966) classifies lakes according to their water budget as controlled by inflow and outflow from and to rivers and the atmosphere.

Genetic Lake Classifications

There is a third group of classifications, this one based on the origin of lakes. Examples are by Harding (1942), Hutchinson (1957) and Humphrys and Veatch (19--). Like all genetic classifications, they provide little information of relevance to current processes and management, such as microclimate, flow, nutrient status or size. However, since the formation of lakes and of landscapes are closely linked, a genetic classification might be able to store information on surficial geology and lake morphology, especially when used alongside descriptive and functional data.

Parameters for Lake Classification

While land and lake classification differ from each other in parameters and in level of detail, there is, nevertheless, a recurrence of many criteria from one classification to another. These trends are listed in Table 8, wherein they are grouped either according to their natural or to their parametric associations. There are marked differences between one criterion and another. Some of them are simple, scalar quantities like total dissolved salts. Others are the calculated results of a formula containing several measured variables, like flushing rate. A few, such as lake origin, are non-parametric. Some are scale-dependent such as shoreline development, which for any given lake shape increases with the scale of the base map used in its calculation. Thus even having identified the qualities to be measured, there remains the difficult problem of applying meaningful and compatible quantified scales or class intervals to them.

Before defining parameters, however, there is the perhaps greater task of judging which properties are most important to a land and water survey. Logistical sanity and efficiency of data storage demand that only limited data be collected for all lakes within extensive areas. In effect this requires the use of remote sensing as the primary data source, with aerial and ground reconnaissance, and ground and water-based monitoring reserved for verification and for representative detailed sampling of sites and dynamic information. It is clearly impossible, therefore, for a land survey to provide a detailed data base for management of every lake in an area. A more viable role for land surveys is regional scale planning of lake resources, a process which requires a spatial grouping of lakes of similar nature and use potential.

"We seldom are interested . . . in making comparisons among lakes of vastly different

Table 8: Themes in Lake Classification.

GROUP	CRITERIA	APPLICATION
Land Environment	Origin	History, Environment, Nutrients
	Shorelines, Backshores: Materials, Vegetation	Nutrient Supply
	Shore Processes	Contemporary Change, Shoreline Land Use Impacts
	Streams, Stream Debris	Water Budget, Nutrient Supply
Lake Morphometry	Length, Width, Fetch Area Depth (mean and max.)	Size, Volume, Flow, Currents
	Shore Profile % Littoral Area Shoreline Development Insulosity	Aquatic Habitat
Water Regime	Number and Size of Streams Flushing Rate, Hydroclimate Water Levels	Water Budget Replenishment Nutrient Supply
	Currents, Waves Ice Chronology Thermal Structure	Mixing Nutrient Distribution
Water Quality	Secchi Depth Total Dissolved Salts Phosphorous, Nitrogen, pH Hypolimnion Oxygen	Trophism Nutrients
	Standing Biomass Chlorophyll 'a' Biomass Production Life Stage	Productivity

regions . . . One of the first and most logical steps toward grouping of lakes is on a regional basis . . . The problem as always is what do you include in a region? What are the conditions that establish the boundaries? A geographical segregation into natural regions must consider geologic, edaphic, climatic, vegetational, etc. conditions" (Donaldson, 1969, p.172). Donaldson quotes Margalef (1958) in suggesting the following requirements for a regional lake typology; a relatively constant mineral concentration, a similar history, similar evolutionary phases and similar terrestrial conditions such as geologic substrate. Both Donaldson and Margalef noted that regional groupings must allow for variations in number, size and succession stage within a population of lakes.

On the basis of an empirical classification of one hundred and fifty lakes in the north central United States, Winter (1977) reports that precipitation-evaporation balance, the quality of local groundwater, inflow and outflow of streams, depth, the ratio of the lake area to its basin area, local relief and regional slope are the major variables determining the hydrologic setting of lakes. Much of this information is similar to that contained at various levels in an ecological land classification. For example, although land regions are traditionally mapped through expressions of vegetation, there is usually some climate data available from which moisture balances can be derived. Regional slope can be calculated from topographic maps at the level of land districts. Local relief and bedrock

information is usually classified at the presently defined land systems level. It seems that there is agreement in theory and from practice that broad-scale characterizations of lakes are both desirable and possible, and that they are compatible with the methodology of ecological land classification and survey.

While these authors use the term "region", their principles can extend to any scale of mapping, not just of ecological land regions. In other words, limnologists use the term region in the sense of "broad area", or "large tract of land". If a land survey can group water bodies, spatially or otherwise, and give some idea of their nature, then this is a sufficient and worthy contribution to resource planning and impact assessment. Selection of measured properties and their related parameters should depend on the nature of an area's water resources, the logistical and air photo support available, and the perceived purposes of a land survey. The only minimum requirements of a land survey for lake resource planning are that the data base can contain or generate preliminary information on a lake's environment, its physical dimensions, its hydrology, and its nutrient status and potential productivity, and then be able to compare these properties with other lakes in the same or neighbouring region.

LAKE INVENTORIES

Large portions of Canada have been subjected to systematic land survey (Figure 2). For the lakes in some of those areas there is some data, even if only of area, shorelines and backshore environments (e.g. CLI, 1970; Jurdant, 1977a). In contrast there is a relatively small but growing number of lakes which have been the subject of intensive research or management, most notably the Great Lakes and the Experimental Lakes Area near Kenora, Ontario. Systematic, large area, general purpose lake inventories, however, seem to be rare. In the document search for this paper, many classifications were unearthed, be they for province, state or region. However, most of them were for restricted, research application rather than for an extensive operational survey.

In Canada, the Department of Environment Inland Waters Directorate has published an Inventory of Canadian Freshwater Lakes (Environment Canada, 1973). This nationwide survey is aimed at volumetric measurements for all Canadian lakes of 100 km^2 or more. Provincially, there has been a Fisheries Inventory for Manitoba (Nelson and Faulkner, 1971) and in Ontario there is an ongoing Lake Survey Program, also for fishery purposes (Dodge, 1976).

	Environment Can. Inland Waters	Ontario Lake Survey	Manitoba Fisheries Inv.	Florida Lake System
Total Area, including Islands	X	X	X	X
Number of Islands	X			
Area of Islands	X			
Net Water Surface Area	X			
Maximum Dimension; Length	X		X	
Orientation of Maximum Dimension	X			
Width			X	
Depth, Maximum and/or Minimum		X	X	
Bathymetry		X		
Volume		X		
Inlets, Number, Size and Flow			X	X
Outlets, Number, Size and Flow			X	X
Drainage Area			X	X
Water Elevation	X			X
Backshore; Environment; Relief		X	X	
Foreshore; Environment; Relief		X	X	
Shoreline Development		X		
Aquatic Vegetation			X	
Temperature; Average; Profile			X	
Conductivity; Total Dissolved Sales		X	X	
pH; pH Profile		X		
Alkalinity		X		
Gases; 0_2; 0_2 Profile		X		
Clarity; Secchi Depth		X	X	
Public Access				X

Table 9: Some Lake Inventories.

In the United States, Florida has a completed gazetteer of lakes, although its information is limited to the needs of recreation planning (Florida Board of Conservation 1969). Table 9 lists properties collected for each of these inventories.

SUMMARY

By combining these limited experiences in land and lake survey, it seems that planning of most lake uses requires data on terrestrial environments and on lake morphometry, but that detailed water regime and quality data is needed mainly for commercial fishery development. If dynamic and trophic indicators can be determined for a carefully stratified sample of lakes in any region, then there is a viable role for lake inventories based largely on air photo interpretation of terrestrial and morphometric properties. In describing some methodological problems of inventories of lakes, mainly to do with the choice of a lower size limit for consideration as a lake, Szesztay (1966) concluded that there should be two parts to a lake inventory: *"1. a general survey on all lakes surpassing in extension the specified lower limit, but confined to morphometrical data that can be determined mostly from general geographical maps; 2. an additional survey limited to hydrologically well-studied lakes, containing all basic hydrologic data"* (Ibid. p.894). Considering the classifications and inventories reviewed above, this last idea is in fact being pursued in parts of Canada, albeit by chance. One role of ecological land surveys, then, should be to extend general lake surveys, with the aid of remote sensing and other support, and to produce limnologic data that can be integrated with environmental qualities for resource planning and management purposes.

Chapter Five

RIVER CLASSIFICATIONS AND INVENTORY

Every rill is a channel for the juices of the meadow. Last year's grasses and flower-stalks have been steeped in rain and snow, and now the brooks flow with meadow tea. . . .

Thoreau

THE ECOLOGICAL SIGNIFICANCE OF RIVERS

One can hardly exaggerate the social significance of rivers. Historically they have played a vital role in settlement and boundary-making. They transport and supply water for consumption, for industrial processing and for irrigation. They form routes for exploration and the shipment of goods. Fishermen, swimmers and canoeists use rivers in ways that relate them to their natural surroundings. Rivers are therefore resources not only for the water they carry but for more abstract contributions to human affairs.

To scientists, if not to laymen, the ecological significance of rivers is as great as their social importance. Rivers and their waters are resource units for the milieu they provide for fish habitats, for viewing and for riparian vegetation for ungulates. Rivers and flow regimes are dependent on and integrators of land and climatic events within watersheds. They are active agents in landscape change, and in being so they indirectly control other processes, such as when air flow is orographically controlled or when glaciers flow along pre-existing valleys. Rivers destroy and create a variety of habitats in the course of erosion and deposition. Finally, rivers are the sensitive indicators of environmental stress, as when deforestation or overgrazing leads to siltation, or when mercury-laden waters are transmitted many miles from their point of contamination.

RIVER CLASSIFICATION

Introduction

Just as lakes are diverse in kind, so too are rivers (Figure 13), and just as there are numerous attributes which singly or in combination can be used to characterize lakes, so is this also true of rivers. With rivers, though, there is an added problem. They integrate into their own hierarchies called drainage systems. For ecological land mapping this problem poses two aspects. Firstly their natural hierarchy is essentially related to slope, whereas ecological land hierarchies are structured on patterns of landforms, soils and vegetation. Secondly, the progressive joining of channels creates difficulty in land mapping because key properties of flowing water are scale-dependent. At a land system level of mapping, for example, appropriate mapping criteria might vary between small streams of local origin and a major river transecting an area. On normal, medium scale air photos these criteria would be, respectively, related to drainage pattern and channel morphology. Thus in selecting classifiers for the ecological mapping of rivers, the purpose and scale of the inventory have to be more carefully matched than for lakes.

The relations between fluvial environments and the scale of land and river systems are represented in Table 10. Also included are possible classifiers, each having some functional significance at their respective scale. The bars illustrate the range of scales over which these fluvial systems are found.

Runoff Response

At small scales flow systems are characterized by precipitation, overland flow and runoff responses of small watersheds. These processes and their controls are discussed by Wisler and Brater (1959) and in Gray (1970). Runoff events are the result of interactions between microclimate, physiography and vegetation. Even though runoff events are individually controlled by antecedent moisture conditions and the intensity and duration of precipitation, ecological land surveys are suitable for predicting relative runoff and water relations of units of land. Existing ecological land survey methodologies are already, in a sense, capable of delivering hydrological data at the surface runoff level of the hierarchy of fluvial systems.

Hydraulics

Once overland flow becomes confined into channels, a new set of features is added to the water system. As laminar flow gives way to turbulence, channels are created through which sediment moves in suspension and sometimes in

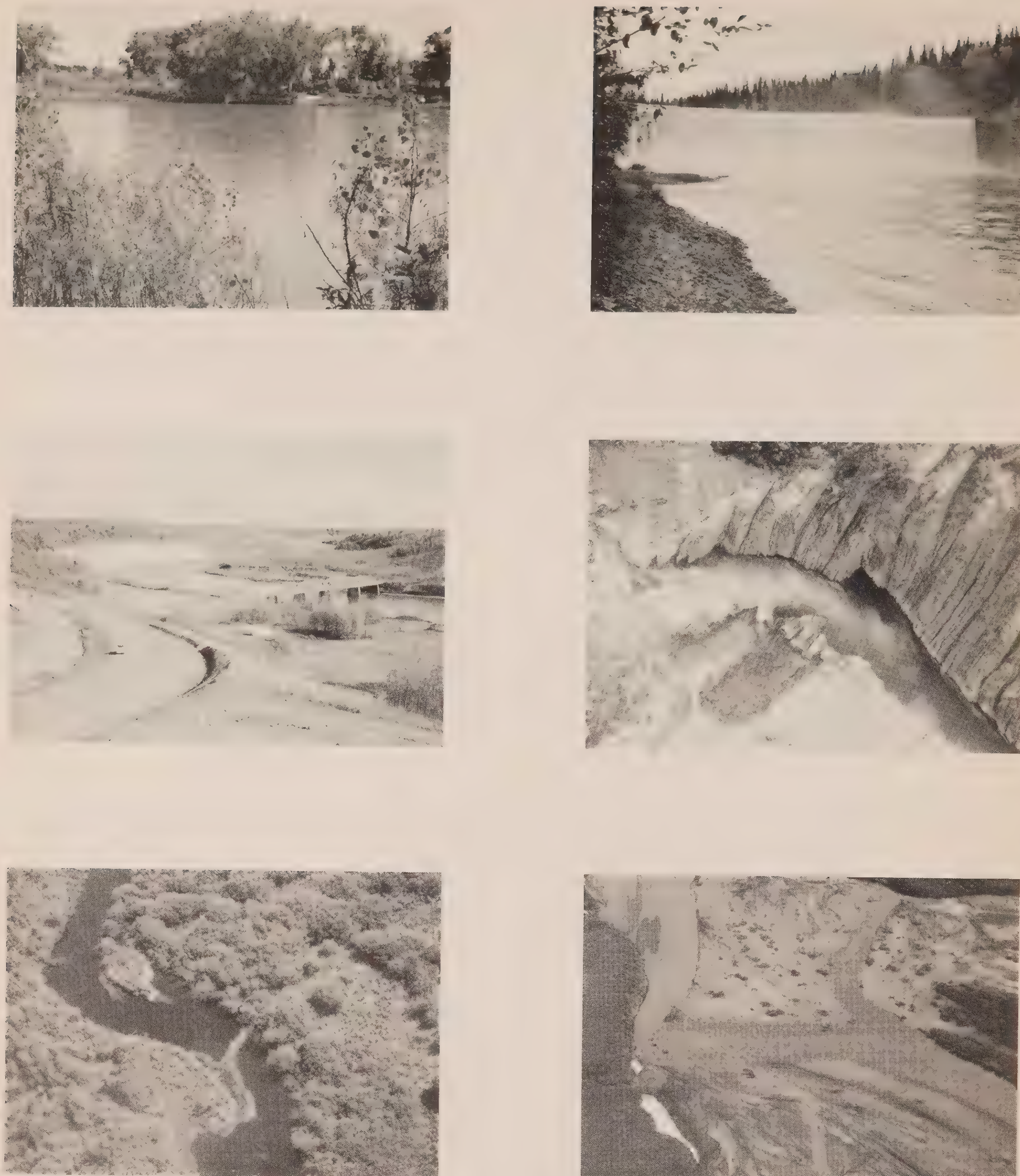


Figure 13: The Variety of Canadian Rivers

Table 10: A Hierarchy of Fluvial Environments.

FLUVIAL ENVIRONMENT	FACET STAND / LAND PHASE / OVERLAND FLOW	RILLS	LANDFORM / LAND TYPE / CHANNELS	LANDSCAPE PATTERN, UNIT / LAND SYSTEM / RIVERS	PHYSIO-GRAPHY / LAND DISTRICT / BASINS	ECO-CLIMATE / LAND REGION / BASINS	SUITABLE CLASSIFIERS	CONTROLS
RUNOFF RESPONSE	←	→					Length of overland flow Drainage density Infiltration capacity Local relief	Physio-graphy Soils Vegetation
HYDRAULICS		←	→				Bedforms Roughness	Discharge Gradient Sediment Parent material
REACH HABITAT			←	→			Bank form Riverine vegetation Bedload Rifflies, pools, falls, rapids Depth, width	Physio-graphy Channel dynamics Debris load
CHANNEL PATTERN			←	→			Sinuosity index Pattern class	Debris load Energy relations
VALLEY FORM			←	→			Plan pattern Cross shape Terraces Under and over-fit	Tectonic history Geomorphic history Eustatic history Geology
DRAINAGE TOPOLOGY				←	→		Bifurcation Order Magnitude Basin shape	Growth Geology
DRAINAGE PATTERN					←	→	Pattern River capture	Geology
RIVER REGIME						←→	Lag time Basin size Precipitation Snow Base flow Etc.	Climate Physio-graphy

mobile beds. The resulting bedforms and bed roughness, alongside gradient and channel size, display strong correlations with discharge and hydraulic conditions (Henderson, 1966). Apart from their hydrological importance, bed conditions are of ecological significance, such as for fish habitat, especially spawning, for groundwater relations, and for small craft navigation.

For the practical purpose of rapid resource mapping, natural channel hydraulics can be classed as alluvial or non-alluvial, having, respectively, mobile or non-mobile bed materials. Mobile beds display a variety of forms depending on velocity and depth. Unfortunately these bedforms are visible only under rare circumstances, so little further distinction can be made in the field. Furthermore, their dependence on day-to-day hydraulic conditions means that the bedforms present in a stream are likely to vary seasonally and even daily.

By their very immobility, channels with non-mobile beds do not conform to short term hydraulic properties of streams. Like all channels, however, they present a resistance, called Roughness, to the passage of water. Empirically derived values of roughness are often used to describe the physical state of a channel in equations relating velocity, wetted perimeter and slope. Both Henderson (1966) and Gray (1970) tabulate a variety of Roughness values. Barnes (1967) illustrates these values for a wide selection of natural channels. For ecological land survey, the channels of a land area could therefore be characterized by classes of bedform such as alluvial, smooth, moderately smooth, rocky or rough, very rough, or some alternative set of classes according to local needs.

Reach Habitat

Although hydraulic properties and processes occur in channels of all sizes, they are manifest in small phenomena such as ripples, dunes and boulders. At a larger scale, these features integrate with each other and with bank morphology, riverside vegetation, erosion and deposition processes and the depth and width of channels. Together they determine the appearance of a stream reach, here called its *Habitat*.

A reach can be defined as a segment of a stream or river wherein various sites display broadly similar properties and appearances, so that a reach habitat can be typified by one site within it. Channel pattern, in comparison, requires an aerial or cartographic context for appreciation. Also by way of comparison, whereas runoff response is important as being the land's ability to retain or to yield water, reach habitat is vital to aquatic mammals, fish, angling, boating, viewing, navigability and fordability. Interestingly, the more fully developed methods of stream inventory intended for resource planning and management tend to focus on the reach level. In contrast, research into the physical aspects of fluvial systems has often avoided this level in favour of others. Whatever the reason, because reach habitat classifications are intended or used largely for surveys leading to planning and management of one or more river resource, they are discussed in the following section on river inventories.

Channel Pattern

Channel pattern implies the plan shape and form properties of a reach, and is exemplified by the terms braided, meandering and straight (Leopold and Wolman, 1957). With the exception of slope processes, geologists, geomorphologists and engineers have given more attention in recent decades to channel pattern than to any other aspect of fluvial processes. There is a plethora of channel pattern classifications, ranging from the genetic (Melton, 1936) to the descriptive (Galay et al, 1973; Kellerhalls et al, 1976) to the functional (Schumm, 1963). Along the way there has been an equally large number of parameters and quantitative relations developed to describe the patterns of flow systems in general and of meanders in particular.

This interest has stemmed from the ubiquity and scale-independence of meander geometry and energy relations, phenomena which occur in a wide variety of environments from supraglacial to alluvial steams, from ocean currents to lunar rills, and even to electromagnetic propagation (Thakur and Schiedegger, 1968).

The account of river types in Canada by Galay, Kellerhalls and Bray (1973) and the ensuing classification of river processes by Kellerhalls, Church and Bray (1976) are particularly interesting for three reasons. Firstly they lend some Canadian background to the objective of this paper, namely the discussion of ecological classifications of water bodies in this country. Secondly their report illustrates that many features can be used to describe either reach habitat or channel pattern depending on the authors' wishes and local circumstances. Thirdly there is presented a wide assortment of fluvial properties and landforms, all of which are of some potential use in resource management decisions. Unfortunately they are perhaps too numerous to be included collectively in a workable resource data bank. The authors discuss hydrologic regime, ice regime, channel materials, channel stability and channel

dimensions. There are also various classes of geomorphic setting such as the degree of confinement and of meandering, the presence of bars and of islands, the characteristics of the valley walls and the valley flat, and other special features like log jams and knickpoints. The authors also stress the diversity of types along rivers.

The land classifier is therefore faced with a two-fold problem, that of selecting a mapping scale and of selecting properties to map at that scale. For reasons similar to those stated for land/lake surveys, a selection of parameters is best founded on a remote sensing interpretation which obviates the need for specialized geomorphic or hydrologic expertise, and which is supplemented by ground truth at selected sites.

Valley Form

Since river reaches nearly always occur in valleys, it is often meaningless to describe the one without the other. Similarly, processes along rivers control channel patterns and, in the long term, valley form. Thus reach habitat, channel pattern and valley form classifications are inextricably linked, and so much of the preceding discussion encompasses valleys.

Classifications solely of river valleys tend to be genetic, as when cross-sectional shape is used to discriminate between normal fluvial ( ), semi-arid ( ), and glacial ( ) histories. Valley shapes have also been used to classify landscapes according to their stage of evolution, be it young, mature or old (Davis, 1890), to their tectonic history in terms of rates of uplift relative to downcutting (Penck, 1924), and to their hydrologic history, such as between overfit and underfit streams (Dury, 1970). However, with the possible exception of data for interpretive guides to scenic areas, these genetic approaches promise little of relevance to contemporary land management. This is mainly because genetic classifications rely upon subjective interpretations of physical criteria to elucidate past events, whereas ecological land classification follows a descriptive approach to contemporary phenomena.

Drainage Topology

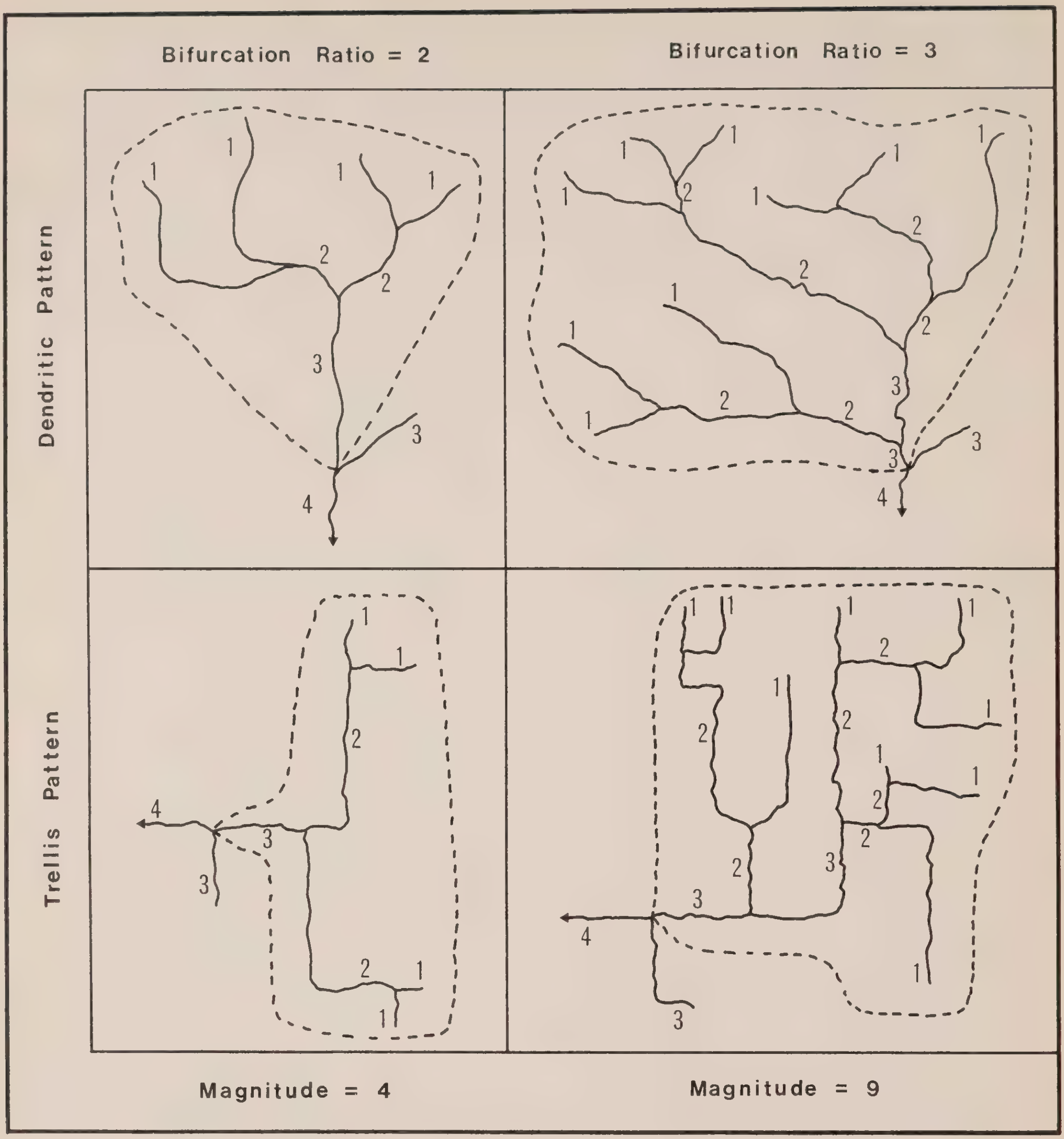
River channels and valleys join with one another to form drainage basins. The integrated properties of basins can be described either by pattern or by topology. Drainage topology concerns the statistical properties of stream segments within a basin, and is an approach to the study of stream networks introduced by Horton (1945). He established a hierarchic numbering system whereby headwaters are segments of order 1, where two first order segments join to make a second order segment, and so on (Figure 14). Basins of, say, order 3 are defined as being all the land which ultimately drains into any part of a third order stream. Third order basins must therefore contain at least two basins of order 2, and also extend downstream until the third order trunk stream meets its match and is promoted to the fourth order. On average, each increase of stream and basin order requires at least a trebling of the total network.

Fluvial systems had been thought to be random, chaotic features. The merit of this and other stream ordering techniques is that they establish principles of extreme regularity in fluvial systems. Numbers of streams, stream length, basin area and stream order relationships prove to have semi-log or log-log relationships of high correlation. It has since been demonstrated that truly random processes in fact generate highly ordered systems, such as drainage networks and meanders. Stream ordering techniques have greatly advanced our knowledge of the laws concerning the form and growth of drainage networks.

While having been successful for research on small drainage systems, network analysis is unsuitable for extensive ecological land classification and mapping. It is far too time consuming, nor does it contribute directly to resource planning and management interests. Given the nature of Canada's landscape and the relative paucity of well-adjusted streams and valleys, drainage systems would have to be mapped at land district or regional levels in order to generate orders large enough for statistical significance. The recent glaciations have also created disordered stream systems, such that the statistical basis for network analysis is absent.

Drainage Pattern

The tedious nature of drainage network analysis rests on our inability to perceive topologic properties; the human eye cannot perceive large numbers or linkages at a glance. Instead, much counting and some arithmetic are minimal requirements. Drainage patterns, on the other hand, concern the geometric arrangements of streams and their tributaries. They can be readily perceived according to one or other qualitative types because the eye is able to recognize angles, linear elements, and repetition. Zernitz (1932) and Parvis (1950) noted that drainage patterns are usually related to geology, soils, or the history of drainage



PATTERN AND TOPOLOGY IN DRAINAGE NETWORKS OF ORDER 3

Figure 14

development. In fact, drainage pattern recognition is an accepted technique of interpreting air photos for underlying materials. For example, dendritic patterns (Figure 14) usually indicate a drainage system on horizontally uniform rocks. Trellis drainage often develops on tilted sedimentary strata; tilted basalt lavas or between sequences of parallel moraines. Thus although drainage patterns have significance for ecological land survey, their meaning is normally stored in terrain data. Only in unique or rare cases does storing drainage pattern data *per se* seem worthwhile.

River Regime

Drainage systems of any scale can be evaluated hydrologically. Most commonly, however, this is done at one of two levels. One is on small watersheds where single weather events affect most or all of a basin. Hydrologic responses on small basins reflect stable geologic and soil properties and the phenology of vegetation. Runoff for such basins can be characterized according to contributions from precipitation directly onto channels, runoff from land surfaces, interflow through soils, and groundwater discharge (base flow) through the sides of channels (Wisler and Brater, 1959), or by basin yield and its percentage of precipitation. These factors are all controlled in a manner similar to runoff response as discussed in a previous paragraph. Thus ecological classification of land includes variables appropriate for comparative estimates of runoff from land types and land systems.

Large basin runoff is more commonly characterized by climatic control, vis-à-vis total annual flow, seasonality of rainfall, snow storage, seasonal melting, and latitudinal zonation of these processes. Together they distinguish, say, west coast mountain streams with two runoff peaks corresponding to winter rains and summer ice and snow melt, and southern Prairie rivers where long east-west rivers thaw in a short time to produce pronounced discharge peaks in the spring (Mackay, 1966). These broad-scale river classifications are based on a variety of hydrometric data, such as discharge, water levels, sediment load and ice chronology, data which is collected on a regular basis at many locations throughout Canada (Campbell, 1975). Supplementary collection of this kind of data exceeds the operational limits of ecological land survey, where the emphasis is on delineating and describing relatively small parcels of land on the basis of their ecology. In remote areas, however, several seasons of hydrologic as well as climatic data may be needed to plan field operations and to subsequently describe land regions.

RIVER INVENTORIES AND THE REACH

Inventories of rivers have several manifestations. The most conventional deal with the rivers themselves and the water flowing within them. The collection of streamflow, sediment transport and ice data, water quality and hydrographic data across Canada is described by Campbell (1975). Similar data is also collected by water resources and fisheries branches of provincial governments. These are the kinds of data referred to in the final part of the foregoing discussion on river classifications. These hydrologic inventories are not adjuncts to land surveys but parallel investigations equally essential to sound regional planning and management.

Another approach is to label land areas according to the river system that drains them, in effect delineating the hierarchy of drainage areas, as has been done in Manitoba (Fedoruk, 1970). This kind of inventory depicts land boundaries rather than flow properties, and as such is a method which interfaces between hydrological and land surveys. The same may also be said of grid network sampling of terrain data related to hydrology, as represented by the Hydrologic Square Grid System (Qurishi, 1973). While both of these land-based approaches to hydrologic inventory have meaning for regional level decision-making, neither provides the accuracy or precision necessary for describing individual units of land in an ecological survey.

The preceding techniques aim at characterizing hydrologic functions of large areas. An alternate class of river inventory is concerned with individual reaches of rivers and details of their site characteristics. These inventories tend to differ from one another with respect to the parameters used. The spectrum of river reach parameters is indeed so great that a single table of comparative inventories, like Table 8 for lakes, is not practicable. Table 4 describes one such river inventory, that of the Environment and Land Use Committee (now the Resource Analsysis Branch) in British Columbia. Other examples come chiefly from the United States. As parts of complete land surveys, river reach data is included in both the Sandpoint Land Use Planning methodology (USDA, 197-) and the Ecoclass method for classifying ecosystems (USDA, 1973).

All of these methodologies share a catholic approach, including data on flow properties, water quality, landforms, channel form and vegetation. Even where the context is limited to the rivers themselves, this eclecticism

continues to hold. For example, in the evaluation of natural rivers, Morisawa (1969; 1971) recommended inventorying river data on fauna, vegetation, geology, hydrology and culture, such as history, anthropology, aesthetics, and local and national interest. Although more limited in intended application, Leopold (1969) makes a quantitative comparison of some aesthetic factors among rivers which is more complete than other river inventory methods cited here. Leopold includes field data on physical factors of channels and their drainage basins, on biology and water quality, including floating material, on land flora, on evidence of pollution, including litter, and on human aspects such as access, artificial modifications to channels, vistas and historic features, for a total of 46 parameters.

The approaches of Morisawa and of Leopold have been closely paralleled by the Wild Rivers Survey (Indian and Northern Affairs Canada, 1973). Twenty-one rivers were surveyed by canoe teams, each completing a comprehensive data sheet at sites representing reaches of 200 to 500 yards. Forty-two parameters were recorded, ranging from site elevation to water temperature to campsite availability.

Not only the Wild Rivers Survey but other methods of assessing the recreational potential of waterways have been described and evaluated by Hooper (1977a). The data sheets of Leopold (1969), the Wild Rivers Survey, Morisawa (1971), Craighead and Craighead (1962) and Dearinger (1968) are therein reproduced in full. Hooper himself has proposed a classification for the evaluation of mountain rivers for canoeing and kayaking (Hooper, 1977b). Included are a method of shoreline typology which measures height, composition, slope and shoreline vegetation type and density, a rating system for white water canoeing, and procedures for the evaluation of portages and campsites. The level of detail of this and the other similar inventory methods is equivalent at least to the land type or land phase level of ecological land classification. Thus as already observed in this paper, a problem often to be faced by the land classifier is to derive a simplified legend for various scales of work, while retaining usefulness for a number of interpretations.

The literature on fisheries offers just as diverse an array of phenomena and relationships considered to be of importance as does that on recreation, aesthetics and historical environments. In a review of the *"ecological factors affecting fishes"* Hynes (1970) concludes that *"the most important abiotic factors (affecting fish) are temperature, both directly and, for cold-water fish, indirectly through its influence on oxygen consumption, rate of flow and fluctuation in discharge, and the availability of suitable shelter. The chemical content of the water seems to be of relatively minor importance"* (Ibid, p.340). Hynes continues (p.341) . . . *"It is thus possible, in areas which have been well studied, to describe rivers and streams in fairly general terms and to list with some degree of confidence the fish species which are likely to be found there."*

The lesson for ecological land surveyors is that if biologists can provide a local list of fish species and habitat requirements, it is relatively easy to delineate favourable habitats by virtue of their physical properties. More recently Platts (1976b) found that *"stream depth, width, and the elevation of the stream channel were the most important evaluated variables controlling fish populations"* (Ibid, p.267). Platts also points to the holistic nature of the natural environment. As an example, he cites the apparent effect that increases in fine sediment load increase fish populations. In practice, however, fine sediment increases downstream in most rivers, along with depth, width, and reduced elevation and gradient (Ibid. p.281). Thus the consideration of a limited number of variables may miss a co-variance among those variables which is in fact dependent upon some underlying principle factor.

In general, then, there is agreement that factors which vary progressively along a river are important to fish populations. Channel size, elevation, temperature and constancy of flow all fit this model. In one point, however, there is disagreement. Where Hynes finds that availability of shelter is important, Platts states that (Ibid, p.279) *"streambank condition ratings had no detectable influence and accounted for an insignificant amount of the explained variation of total fish population."* This difference of opinion may derive from the general nature of Hynes' text, as compared to the local, watershed, study of Platts. It may also be that the meaning of shelter differs between the two authors, from eddies and back-currents to overhanging trees, i.e. shelter from flow and the sun respectively.

Like limnology, the science of rivers does not present a unified preference for a single set of detailed parameters. For ecological land classification and survey, therefore, one may conclude that, for fisheries applications,

rivers can be classified on the basis of simple criteria describing their physical appearance.

SUMMARY

From the discussion of river classification and inventory, there appears to be three points at which land survey can feasibly and usefully include data on flowing water. The first, runoff response from small areas, is and can be included in view of the established nature of ecological land classification. At the other end of the scale, large river systems are described according to long-term discharge monitoring and by drainage pattern according to geology. The latter is simple to determine from maps and air photographs, but is of little ecological significance once the geology itself is established, as is usually the case anyway. The former, river basin discharge, is essential information but of the type which can present difficulties of integration in that drainage basins are not always concordant with land regions, and in that regime is time-dependent and cannot be witnessed in a single field season.

The third approach to land/river integration appears to be at the land type or land system (as currently defined) level, depending on the scope and logistics of the survey. At these scales it is practicable and useful to examine the habitats of channel reaches and their valleys. Actual parameters selected should be determined in accordance with the local landscape and the available logistics, be they air photo interpretation, helicopter, reconnaissance or complete field survey.

Chapter Six

SHORELINE CLASSIFICATIONS AND INVENTORY

I will arise and go now, for always night and day
I hear lake water lapping with low sounds by the shore;
While I stand on the roadway, or on the pavements gray,
I hear it in the deep heart's core.

Yeats

THE ECOLOGICAL SIGNIFICANCE OF SHORELINES

Shorelines are the meeting place of land and water, be it sea, river or lake. Because they consist of contrasting media, shorelines display great sensitivity to activity in any one or other of their major components. Strong terrestrial controls are revealed by headlands or resistant materials, sedimentation from erosion sources, and a variety of land uses and engineering works. Aquatic processes are revealed in cliff erosion, longshore drift, spits and marshes. Further, the union of land and water is often touched directly by wind, as when beach sand is deployed into a line of dunes.

Thus even in the absence of tides, shorelines are often complex spatially and variable temporally, whether due to seasonal events, seiches, or long term changes in patterns of use. Shoreline types are many and varied (Figure 15), each one containing a number of interdependent ecological niches commonly embraced by a single geomorphic process-response system. Sound planning and management of littoral environments therefore depends upon accurate recognition of both ways of perceiving land, by morphologic systems and by process systems. In fact, it is partly with shore lands in mind that the definition of "land system" herein proposed (p.19) was construed; commonality or interaction between processes is more important to the understanding and management of natural resources than the mere repetition of morphologic elements.

Apart from their general ecological significance, shorelines are major attractors of human activity. They provide the sites for centres of aviation and commercial fishery, of consumptive water uses like coolant for power generation, of direct contact uses such as swimming, boating and sport fishing, and for non-contact uses like cottage development and landscape viewing. An understanding of shoreline types and process is also fundamental to the classification of lakes from aerial photographs. Since light is poorly reflected from water, most remote sensing interpretations of lakes are based on nearshore, shoreline and backshore features.

Because a shoreline can be coastal, lacustrine or riverine, a great deal has been written about them and their classification. An examination of the related literature reveals, however, that the majority are concerned with coastal shorelines, and at that for research purposes (Silk, 1975). Relatively few classifications or inventories have been construed for inland shorelines. Although some of the foregoing land, lake and river classifications and inventories consider the lands adjacent to the water bodies, a shoreline must surely be given independent consideration wherever mapping scale permits and where the water body is large enough for wave and current dynamics to introduce littoral processes and habitats. Examples are cliffs, beaches, lagoons, dunes and sand banks. In contrast, the essentially unaltered rock shores of many of Canada's small lakes could perhaps be represented by an adequate description of the land itself and a classification of the whole lake. Thus the need for classifying shorelines arises with lakes and rivers of large size or whose littoral materials are easily modified by waves.

SHORELINE CLASSIFICATION

Introduction

The majority of shoreline classifications derive from research on sea coasts. Lake shoreline classifications are relatively rare and, as a group, tend to be for inventory, planning and management purposes.

Shoreline Component Classifications

Lakeshore classifications follow two main approaches. The first describes a variety of properties for each of the major components of a shore, such as the backshore, the wet-beach and the offshore zone. This approach is suitable for large scale, detailed inventories such as at the land phase level of ecological land survey. A simple example is that of the Ontario Recreation Land Inventory (Cressman,

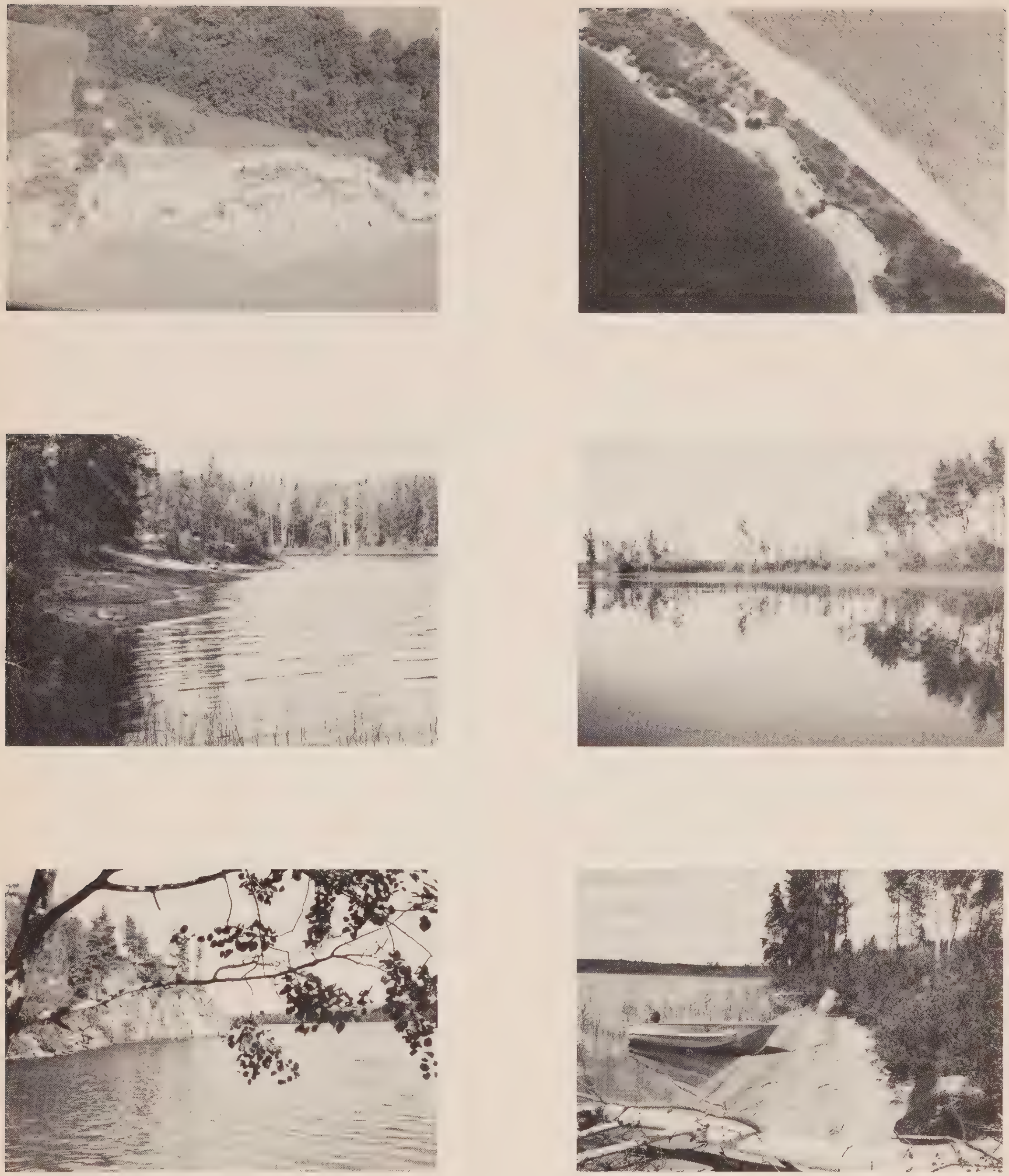


Figure 15: The Variety of Canadian Shorelines

1971) which identifies shorelines units of at least 660 feet length as the basis for backshore and wet-beach slope and materials data. Most of the data for each unit is, however, an assessment of capabilities and limitations for recreation purposes, and is therefore not appropriate to the descriptive, objective approach of ecological land surveys.

Within this approach of describing the components of a shore profile, Bowers et al (1942) provide a very detailed, qualitative classification for inventory of Michigan's Great Lakes shorelines. They identify backshores with respect to morphology, width, modifying features and vegetation, and beaches and foreshores according to materials and width. They reported a total of sixteen combinations, or "shore types". The detail and complexity of their mapping justifies considering this example as being descriptive of shore components, but the authors' recognition of recurring associations parallels the second approach to shoreline classification, that of describing common associations of various components.

Shoreline Association Classifications

While freshwater shoreline classification follows two principal methodologies, recognizing either discrete components or characteristic associations, the method of associations varies according to the objects recognized. Some of these classifications associate topography and materials and can be called physiographic, while others regard materials and geomorphology and are thus geologic in nature. A third group is geobotanic, classifying shoreline units by landform, water relations and vegetal cover.

Physiographic Shoreline Classifications - The classification of Veatch and Humphrys is presented independently of operational application, but is nevertheless derived from their experience of Michigan lakes (1966, p.360; see also Humphrys and Veatch, 19--). It is a physiographic classification which recognizes five shoreline types. The first is of high shores where cliffs of rock, drift or dunes rise from the shoreline. Secondly, there are the cliffless, low shores, such as beaches and beach ridges, which are differentiated by materials such as sand, stones, boulders, rock, peat, marl or clay. Third and fourth are shores of recent water recession and of artificial fill. Finally, Veatch and Humphrys list seven sub-classes of vegetated shores, marsh, bog, shrub, swamp, wooded, weed and artificial vegetation. In all, their five classes incorporate fourteen sub-classes and thirty-five further subdivisions. While starting with a limited number of physiographic units, their complete range is at least as diverse as the Great Lakes shores of Michigan described by Bowers et al (1942).

Under the auspices of the International Joint Commission for boundary waters shared by the United States and Canada, the Canadian Department of Public Works in the 1960's carried out an inventory of Canadian Great Lakes shorelines and land uses (Haras, 1972). Eight shoreline units were recognized on the basis of physiographic association. These shoreline types are recreational beaches, marshes, bluffs, bluffs with narrow beaches, bluffs with stone at the toe, rock slopes, rock slopes with a narrow beach, and beach scarps consisting of grassy banks sloping gently to fifteen feet or more above a beach. At first this classification for *"some 6400 miles of the national shoreline"* (Haras, 1972, p.493) seems excessively simple; however, it is for inventory purposes rather than research. Most of the land and water inventory literature stresses the need for simple classes which can be applied consistently by field crews and easily interpreted by data users. Bowers et al (1942) and Veatch and Humphrys (1966) classifications are cumbersome, whereas those of Haras (1972) and others (see below) are far more pragmatic and appropriate for land survey.

In a different setting, the Interlake District of Manitoba, Baker (1964) established a simplified classification of physiographic shoreline units. Three classes are subdivided into six sub-classes. Low, wet shores are either marsh, wet forest or drained forest. Intermediate shore correspond to ice pressure ridges inherited from the time of glacial Lake Agassiz. Upland shore are either of bedrock or soil. Baker's classification was expressly for a recreation capability inventory, and foreshadows the simplified approach of Cressman (1971) and Haras (1972), the actual classes varying according to the regional setting.

Geologic Shoreline Classifications - The second, geologic, approach to classifying shoreline associations is based on landforms and parent materials, with less emphasis on topographic factors. Examples are by Hands (1970), again dealing with Michigan shorelines, and by Water Resources Branch, Manitoba (1974) and McCullough (1977) in the context of shoreline impact assessment at Southern Indian Lake, Manitoba. Hands presents a simple breakdown, based on air photo interpretation, into seven classes, unconsolidated bluffs, dunes, deltas, rock, marsh, swamp, and low dry plains. The Water Resources Branch, Manitoba

(1974) report a hierarchic scheme of three classes, bedrock, alluvium or overburden, and organic, and fifteen sub-classes. The classifications of these authors are both designed for a distinct environment, so that particular shore classes are not universally applicable. Nevertheless the adoption of a limited number of simple units of associated features lends a useful guide for ecological land survey using remote sensing as the prime data source.

Ecological Shoreline Classifications - None of the above are truly ecological in nature, nor were they intended to be. One candidate for an ecological, or geobotanic classification of shorelines is that of Bishop (1967) who used shoreline associations as a means to classify Florida's lakes (see also Florida Board of Conservation, 1969). Bishop's eight shore types assemble geomorphic and botanic features in ways that depend on active processes. Firstly, sloping swamp forests occur where organic material collapses over dissolving limestone. Consequent shorelines originate in the same way but receive sufficient wave action to remove vegetation. These shorelines evolve into wave-eroded beaches possessing notches or wave-cut platforms. These in turn are succeeded by flat swamp forests as soon as trees recolonize the wave-eroded platform. The final stage in the succession is an open aquatic forest, or swamp, where the platform itself has begun to collapse. Bishop recognizes three other shore types, peat marsh shore, bush shore, and altered shoreline resulting from human action.

The ecologic, process-oriented classification of Florida shores seems possible because of the limited physiographic, climatic and temporal range of environments. If lake genesis is uniform, modifying processes can be easily used to differentiate shorelines according to stage of development. In areas of complex climatic history, or variable geomorphic situations, processes are much harder to incorporate into a simple classification.

SHORELINE INVENTORY

There are many classifications of rivers and lakes which are based on a single theme, or are designed for experimental use by experienced researchers. Shoreline classifications, on the other hand, are designed more to meet policy or surveillance needs and are notably empiric to the features occurring in a region. Thus shoreline classifications for inventory, for example by Haras, Bishop, Baker and Cressman, impact study, such as by Newbury, and research or general purposes, for example Bowers et al and Veatch and Hymphrys, have been discussed as a group.

SUMMARY

There can be little doubt that shorelines are, as a rule, more changeable than other environments. This is because lakes are geomorphic anomalies, or historical hangovers, and shorelines are the battlefield on which nature restores her equilibrium. By the same token, however, shorelines are significant land features only at relatively detailed levels of mapping, such as the land type. At smaller scales, individual shores become collectively submerged by whole lakes and dry land systems.

Despite problems of terminology, it remains important that process-response systems be recognized as the basis for delineating shore lands. Littorally speaking, shoreline classes are usually consistent in scale with land types as defined by the Sub-Committee on Bio-physical Land Classification (1969) and by Jurdant (1977b). Examples of shore *systems* are stretches of rock cliffs which contribute and receive little material from neighbouring areas, and eroding cliffs, with spit, lagoon, dunes and marsh all forming one more or less closed sediment and wave energy system.

Delineating a shoreline mapping unit is one problem; describing it is another. As with the other land and water features, it is recommended that objective, descriptive criteria be used, criteria such as parent material, foreshore type, slopes, exposure to waves, emergent vegetation and indicators of longshore drift. Also akin to features previously discussed, actual classifications and diagnostic features must depend on local conditions, data sources (e.g. air photo scale), supporting logistics and available expertise. In view of these requirements and the ecological basis of various levels of ecological land survey, the method of classification by associations is to be preferred. More detailed shore mapping, such as isolating individual components of a shore profile, appears to be too lengthy for reconnaissance survey, notwithstanding its importance for more exacting work such as impact studies (Newbury, notwithstanding its importance for more exacting work such as impact studies (Water Resources Branch, Manitoba, 1974; McCullough, 1977).

Chapter Seven

CONCLUSIONS

Now I must bore you with certain abstract things, but I hope you will listen to them patiently. I am a man of passions . . . . . Now and then I speak and act too hastily, when it would have been better to wait patiently. I think other people sometimes make the same mistakes.

Van-Gogh

THE NEED FOR AN INTEGRATED LAND/WATER CLASSIFICATION

Lakes and rivers cover more of Canada than many of the components normally considered to be part of the natural landscape. For example, freshwater bodies cover 7.9% of Canada's land area, compared to 6.71% covered by grass and croplands and 0.06% of built-up areas (Energy, Mines and Resources Canada, 1974). By area alone, therefore, water must be considered in the planning and management of our land resources. In order to provide a cost-efficient, comprehensive data base for this planning and management, resource data should be surveyed using the method of ecological land classification, with water information integrated alongside other environmental components. In any given area, water should be considered in importance relative to its occurrence, its variety and its potential usefulness.

Apart from its importance by extent, water is inextricably linked with human affairs, be they domestic, industrial, commercial or recreational. Water is sustenance to all and habitat for much of our flora and fauna. As we intensify and multiply land and water uses, and as we develop and settle more of middle and northern Canada, then good quality, inclusive environmental data will become more than ever a prerequisite to sound planning and management of resources. For these reasons also, it is vital that land and water resource data be integrated into ecological information systems.

Ecological information systems should include traditional data such as stream gauge records, lake quality monitoring and meteorologic data, each at selected reference stations. An important part of an ecological information system, however, is a map of ecologically significant tracts of land at a scale and level of generalization suited to the decisions likely to be made about that land. Whereas both ecological land survey and resource decision-making occur at various levels of generalization, water features must similarly be integrated with land at a number of hierarchic levels.

THE IMPORTANCE OF FUNCTIONAL SYSTEMS AS MAPPING UNITS

As currently used in ecological land survey, land regions, districts and types are based on some control or process system. Land districts, for example, are realizations of physiography and of the controlling influence of geology upon the landscape. Land types and land regions are based upon the recognition of vegetation; they mark the interaction of a set of climate and site conditions at one or many places respectively.

Although not explicitly stated by the Sub-Committee on Bio-physical Land Classification (1969), most of the hierarchic levels of ecological (bio-physical) land classification are based on the delineation of functional systems. Unlike these four levels of mapping unit (the region, district, type and phase), land systems as currently defined are morphologic systems (see Chapter 2). To requote, a "land system" is *"defined as an area of land throughout which there is a recurring pattern of landforms, soils and vegetation"* (Ibid. p.5).

Elsewhere in this paper I have demonstrated that not only must functional systems be used as the basis for resource mapping and decision-making, but also that morphologic systems and their hierarchies can be cumbersome and surprisingly complex. To be ecologically sound and to provide a consistent classification at all scales, I therefore recommend that ecological land survey adopt a functional basis for all hierarchic levels of generalization.

To facilitate this I further propose that the term "system" be used in its true sense, i.e. not restricted to a particular scale of mapping, and that the term "land system" (synonymous with ecosystem) be used to connote a functional unit at any level of generalization. A definition of land system (ecosystem) revised to meet this objective might read as follows: A Land System is a tract of land that would respond as a system to an externally applied event, or whose components would respond in a similar way to a uniformally applied event.

The intent here is that the term land system could be applied as a sliding-scale mapping unit, and that any level in a hierarchic method of land classification is or should be a functional system. The level of mapping formerly called a land system could instead be designated as a land section (ecosection), for which a suitable functional basis for recognition and mapping is the control exerted by surficial geology and associated landforms.

Thus to aid in the integration of water into ecological land classification and survey, and to provide a more consistent methodology to the classification process, I am proposing a modification of the hierarchy of levels of generalization. Ironically, by stating surficial geology as a functional peg for the identification of ecosections (formerly land systems), such a modified hierarchy would in fact compare more closely to recent practice in ecological land survey than would a face value reading of the Guidelines for Bio-physical Land Classification (Sub-Committee on Bio-physical Land Classification, 1969).

A HIERARCHY FOR INTEGRATED LAND/WATER SURVEYS

Introduction

Rivers, lakes and shorelines can be integrated into ecological land survey, using a common set of mapping units, provided not only that we recognize the functional nature of systems at any level, but also that in identifying any level of ecological generalization we accept aquatic features on an equal footing with terrestrial ones. These features are wetlands, vegetation, surface materials, streams, soils, shorelines, rivers, relief, landforms, lakes, geology, coasts and climate. There are other features that could also be considered, although some of them stretch the meaning of the word ecological. These are demography, historical importance, land use and tenure, deep mineral resources, socio-economic factors, community regulations (like zoning), and tectonic activity (e.g. isostasy and earthquakes).

These latter features are not the subject of this paper. Nevertheless, if ecological land survey is to classify and map tracts of land on the basis of ecological unity, tolerance to impact, potential uses and use conflicts, then certainly water must be recognized with equal importance to terrestrial natural resources. If that is accepted, it is hard to see why the same argument should not apply to other factors which are less "natural".

Table 11 shows how land and water features can be used to identify various levels of generalization. These are not definitions, merely features of recognition: the only definition is that of ecosystem (land system) which applies to any of the five levels described here. Table 11 is in effect an index for the construction of a single, integrating set of map units at any designated level. Depending upon the relative importance of certain features in a landscape, be they terrestrial, paludial, lacustrine or fluvial the criteria could be any one or any combination of the features shown.

Ecoregions

In present usage an ecoregion (land region) is essentially an ecoclimatic unit of land, wherein similar site conditions interact with climate to produce characteristic vegetation chronosequences. Lakes and rivers too are climate controlled. Rivers demonstrate the affects of climate in their annual regime characteristics, as when seasonal weather patterns and temperature regimes determine total water yield and discharge peaks. Lakes show climatic influence in their waves and currents, annual turnovers, dates of freeze-up and thaw, and water level changes. And just as land can in turn influence regional and local climate through albedo, orographic influence, forest fires, etc., so too can lakes of medium and large size produce climatic effects. Many cottage owners and evening beach-freaks have, perhaps without realizing it, experienced diurnal monsoon winds. Landsat images provide many examples of cloud patterns corresponding to the outline of large water bodies (Figure 16). Since climate controls both land and water, and since both also provide secondary, feedback controls to climate, ecoregions should be defined on a broader basis than just vegetation chronosequence.

Ecodistricts

Ecodistricts (land districts) are currently defined as subdivisions of ecoregions displaying broad patterns of soils, landforms and geology, including Quaternary geology. To more clearly distinguish them from ecoregions and ecotypes, I propose that ecodistricts de-emphasize soils, and become areas displaying characteristic associations of geology and landforms, i.e. physiography. Since landforms are essentially the product of selective erosion by running water (rivers) or of glaciation, and since glaciated lands are often typified by lakes, then ecodistricts would become virtually *de facto* land/water districts.

Table 11: *A Hierarchy for Land/Water Integration.*

LEVEL OF GENERALIZATION	DOMINANT CONTROL SYSTEM	COMMON FEATURES OF RECOGNITION			
		LAND	RIVERS	LAKES	LAKESHORES
ECOREGION	Macroclimate	Vegetation chronosequence on similar sites	Large basin regime or similar runoff from small basins	Cloud cover Ice chronology	
ECODISTRICT	Geology	Subdivisions of Ecoregions displaying relatively homogeneous associations of landforms & geology	Drainage Pattern or broad patterns of sediment load along rivers and/or river to river	Lake Pattern Turbidity patterns on groups of lakes	Repetitions of shore types corresponding to land ecodistricts
ECOSECTION	Surficial Materials	Large or patterned landforms, e.g. lacustrine plain, moraine complex	Small watersheds (e.g. 1st to 4th order); a Reach of a large river	A lake and its topographic basin, or a series of similar small lakes	Systems of wave - current - sediment - dynamics
ECOTYPE	Site condition	Vegetation chrono-sequence; soil series	Subdivision of a river reach, e.g. meander in a series of meanders, or a stream segment in a small basin	Large inlet; persistent circulation cell within a lake; bay or arm as recognized by typical shore association	Typical shore association
ECOPHASE	Time within steady controls	Vegetation phase, e.g. stand of trees, cover type, soil phase	Specific feature, e.g. bluff, levee etc.	Tiers within a lake, e.g. hypolimnion, areas of emergent vegetation	Specific features, e.g. spit, cliffs, beach, etc.

Figure 16: Large Lakes and Cloud Cover, one manifestation of lacustrine control over climate. Lake Winnipeg, Landsat, 11 August 1975, band 5, approximate scale 1:1,000,000.

Geology and landforms, however, influence water in other ways than the obvious ones of lake and drainage patterns. Sediment loads and water quality, groundwater and base flow, lake turbidity due to shore erosion, and patterns of shorelines are all active and recognizable at this ecodistrict level of perception.

Ecosections

Ecosections (land sections - formerly called land systems) should be recognized as subdivisions of ecodistricts that correspond to tracts of land of a particular parent material or a characteristic mixture of them. Examples might be hummocky moraine complexes, large lacustrine plains, complexes of rock, outwash gravels and till on the Canadian Shield, or extensive areas of upland plateaux and rock pinnacles in the Western Cordillera.

Ecosections may from time to time focus on aquatic features. Candidates for this case are reaches of large rivers displaying a continuity of size, meandering habit, floodplain materials, etc., over several miles. Tracts of numerous similar small watersheds could also be designated as an ecosection, provided that drainage density, valley sideslopes, infiltration capacity, etc., are uniform. If these sorts of conditions are met, it is highly probable that soils and vegetation would furnish a uniform pattern also. Pedogenesis and plants are dependent on the same climatic and substrate factors as runoff and fluvial action. Large lakes and their basins, or series of small but similar lakes, are equally dependent on, and indicators of, a certain landform-surface material association; here too there should be little problem in perceiving unified land-lake ecosections.

On large lakes, such as Lakes Erie, Huron, Superior, Winnipeg, Manitoba, Athabasca, Great Slave, Nipigon, Okanagan, Lesser Slave, Reindeer, etc., it is usual for wind to generate waves and nearshore currents comparable to marine environments. Consequently it is common to find wave-current-shore systems of great size, frequently larger or more dynamic than whole but smaller lakes. Complexes of eroding cliffs, longshore drift and spits, hooks, offshore bars, lagoons and marshes are common to the larger Canadian lakes. These are also vital resources from a number of standpoints, for beaches, wildlife, loss of land to cottagers and farmers, and for their aesthetic qualities. It is important that these dynamic,

integrated systems be delineated in ecological land survey, regardless of any lack of morphologic pattern.

Ecotypes and Ecophases

Ecotypes are determined by a wide variety of site conditions, including surface materials, infiltration and runoff, aspect, elevation, and local winds. Ecophases are merely stages in progressive or cyclic changes which occur on ecotypes. Examples are the stages of vegetation recovery after a forest fire, the phases of soil development in response to climate change, and the individual slope facets which are found in rotational landslides. All of these ecophases are temporary, although their rates of change vary considerably, from years to centuries.

An example of an aquatic ecotype is a river meander. Any fixed point within a meander can expect, over a sufficient time, to experience a chronosequence consisting of levée, channel, point bar, floodplain, etc. Each of these latter components constitutes a fluvial ecophase. In headwater streams where downward erosion dominates lateral meandering, the valley of a stream segment is an ecotype. The channel and valleyside slopes are ecophases, since their detailed form, position and elevation change over relatively short spans of time.

At the ecotype and ecophase levels of generalization, lakes and lakeshores lose their separate identities. A typical lake ecotype is a bay or arm having characteristic chemical, physical and biological water properties, water circulation, and shore associations, such as sand beach with till cliffs, or gently sloping bedrock shores. Ecophases in lakes and on shorelines are illustrated by tiers within a water profile, a hypolimnion, areas of emergent vegetation, beaches, bars and cliffs, etc. Each one of these is a dynamic entity, with periods ranging from days to centuries, but which in changing would not change the overall character of the ecotype or ecosection.

Summary

The foregoing discussion is intended to illustrate how tracts of land and water, at various levels of generalization, can be *recognized*. There is no deliberate attempt to *define*. Only the free-ranging concept of an *ecosystem* can be defined, for how can we define what is a generalization, or perception, of the landscape? For land/water integration, it is only necessary that both of these components be recognizable at specified levels, and that we describe them in ways appropriate to those levels.

PARAMETERS

Once the level of mapping and generalization has been chosen for a specific survey, and once the nature and importance of that area's water resources are known at the regional level, the choice of logistics, techniques and sampling frequency should follow somewhat automatically. Specific parameters must depend upon a wide range of ad hoc reasons, not the least of which is available funding, but it is recommended here that at least each of the themes identified for lakes (Table 8) be represented, and that the parameters and their subsequent manipulation (interpretation) reflect the anticipated uses and developments in the surveyed area. The latter is also advisable for rivers and shorelines although much depends on the mapping scale (Table 10).

SATELLITE IMAGERY FOR REGIONAL AND DISTRICT PERCEPTION

It follows from consideration of parameter selection and from the hierarchy of integration, that some knowledge of an area is a prerequisite to mapping and measurement. This foreknowledge has traditionally been obtained by literature and cartographic review, by local knowledge of personnel involved in the survey, and by prefield air photo interpretation. It is recommended, however, that sequential satellite imagery be used to improve the regional context, to measure dynamic properties of a landscape, and, with these in mind, to produce a preliminary map of ecoregions and ecodistricts as aids to field logistics. At these levels and stages of survey, aerial photography is too cumbersome, too time restrictive, and often out-dated, to allow a full appreciation of extensive and/or dynamic phenomena. Furthermore, many of the criteria described in this paper for the recognition of land/water ecosystems demand a time-series view of the landscape. Often it is only satellite images that can provide this.

Figure 17

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